EVALUATION OF ESTIMATES OF PHOSPHORUS CONCENTRATIONS AND LOADINGS FROM ONTARIO MUNICIPAL WASTEWATER TREATMENT PLANTS

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Evaluation of Estimates of Phosphorus Concentrations and Loadings from Ontario Municipal Wastewater Treatment Plants

0.) Executive Summary:

A study was undertaken to assist the Ontario Ministry of the Environment (MOE) in the development of future management strategies for controlling phosphorus discharges into the Great Lakes from municipal wastewater treatment plants (WWTPs). The main objectives of the study were to evaluate the accuracy and precision of basin-wide estimates of phosphorus concentrations and loadings and to develop recommendations for improving the management and analysis of data collected from municipal WWTPs.

0.1) Status of Phosphorus Control Practices in Ontario:- Long-term averages (1981-1985) for phosphorus concentrations and loads were analyzed for the 96 Ontario municipal WWTPs which are 1 MGD (4546 m3/d) or larger. For the Lake Ontario and Upper Great Lakes Basins most of the phosphorus loading from municipal sources originated from a few large WWTPs. Basin-wide management strategies for these basins should therefore focus on improving performance at the largest WWTPs in the basin. In particular, for the Lake Ontario Basin, the largest WWTPs in the basin--Main, Hamilton, and Humber--were routinely out of compliance in the period 1981-1985 and their performance data should therefore be examined by the MOE on an annual basis to identify trends in performance and operational problems. Municipal WWTPs in the Upper Great Lakes Basin lagged behind in the implementation of conventional phosphorus removal technology.

Further reductions in phosphorus loading to Lake Erie from municipal WWTPs will require that WWTPs consistently operate below the 1.0 mg/L compliance limit or that tertiary treatment be added at more WWTPs. Substantial reductions in phosphorus loading from municipal WWTPs in the Lake Erie Basin will

therefore be increasingly difficult and expensive to achieve. The MOE should examine the feasibility of reducing phosphorus loads to Lake Erie from other sources.

0.2) Comparison of Sampling Methods:- Flow and phosphorus concentration data from intensive sampling programs at the Welland, Waterloo and Galt WWTPs were analyzed to determine how different sampling methods affected mean daily phosphorus concentrations. The results suggest that, in general, mean daily concentrations are not sensitive to compositing procedures. However, for WWTPs which experience problems with phosphorus removal, 8-h composites will lead operators to underestimate mean concentrations. For this reason, the MOE should encourage WWTPs to collect 24-h composites and discourage the use of grab and 8-h composites.

0.3) Statistical Characteristics of Effluent Data:- The 1985 data (flows, effluent phosphorus concentrations, and daily phosphorus loads--the product of daily flow and effluent phosphorus concentration) for the Main, Humber, and Highland Creek treatment WWTPs were, in general, log-normally distributed. However, the Main data departed significantly from log-normality and appeared to be a mixture of distributions representing normal operations and upset conditions.

For all three WWTPs, phosphorus loading was highly correlated to phosphorus concentration, but poorly correlated to flow. The Main data had the highest degree of correlation between flow and effluent suspended solids concentrations and between effluent suspended solids concentrations and effluent phosphorus concentrations, suggesting that the escape of effluent solids during periods of high flow were responsible, in part, for the high levels of effluent phosphorus. Daily effluent phosphorus concentrations and loads for the three Metro Toronto

WWTPs were found to be serially correlated. Assuming that the results from the three Metro Toronto WWTPs are typical, serial correlation should be taken into account for confidence limit calculations when the sampling frequency is greater than once every other day (182 samples per year).

0.4) Evaluation of Load Estimation Techniques:- Results from alternative load estimation procedures demonstrated that the technique currently used by the MOE underestimated loads for hydraulically overloaded WWTPs. For such WWTPs flows and effluent concentrations are correlated. In addition, results from a computer program to simulate the effect of weekly sampling showed that the accuracy of estimates generally deteriorated as the frequency of sampling decreased. A number of load estimation techniques are superior to the one currently used. Load estimates based on the product of the mean annual flow rates and flow-weighted phosphorus concentrations resulted in the best accuracy of the methods tested. Flow-weighting takes into account the effect of correlation between flows and effluent phosphorus concentrations.

0.5) Reporting and Assessing Monthly Compliance:- Currently, the MOE has defined compliance as 1 mg/L as a monthly mean instead of as an annual mean. The reformulation of compliance in these terms increases the uncertainty in establishing a statistically significant difference between the observed mean and the compliance level; ignoring the effects of serial correlation, precision decreased from 4-10% for 1985 annual phosphorus means to 12-21% for monthly means for the three Metro Toronto WWTPs. Monthly means were less precise because fewer samples were used to calculate the statistic and because process variability was higher.

The main technical issues influencing the choice of a statistic for reporting and assessing monthly compliance were also reviewed. Four statistics (the arithmetic mean, the flow-weighted mean, the geometric mean and the median) were evaluated using simulations. In general, none of the four statistics demonstrated greatly superior performance in comparison to the others. A recommendation was made that the arithmetic mean be retained as a basis for assessing monthly compliance because the link between different compliance limits (based on the arithmetic mean) and the total basin loadings has been established. Additional study is required prior to instituting a change in compliance assessment.

0.6) Precision Estimates:- For the Lake Erie and Lake Ontario Basins the precisions of the phosphorus load and aggregate annual phosphorus concentrations were estimated. Based on the level of performance and sampling frequencies in 1985, the precisions of total basin load and aggregate average phosphorus concentration were estimated to be 2-4% for Lake Erie and 5-6% for Lake Ontario. In terms of total 1985 phosphorus load these percentages corresponded to 5-10 tonnes for Lake Erie and 50-60 tonnes for Lake Ontario.

The MOE has proposed to reduce the total load to Lake Ontario by 50 tonnes per year (5%) and to Lake Erie by 30 tonnes per year (12%). For Lake Ontario, the stated objective is likely achievable but not detectable. In contrast, for Lake Erie, a reduction of 30 tonnes per year is detectable but not achievable through the implementation of conventional phosphorus removal technology or improved operation.

0.7) Sources of Bias in Load and Concentration Estimates:- In addition to load estimation techniques, other potential sources of bias in the phosphorus load or concentration estimates were identified. Because the total phosphorus load from the Lake Ontario and Upper Great Lakes Basins are dominated by a few large WWTPs, inaccurate flow measurements at these WWTPs can seriously impact the phosphorus load estimates for the entire basin. Current practices are inconsistent with respect to round-off of summary statistics reported to the MOE. Similarly, there was no consistent approach concerning the inclusion or exclusion of bypass flow in effluent samples analyzed for phosphorus. It was recommended that bypass flows be excluded from effluent samples and that a separate additional study be undertaken to estimate phosphorus loads from WWTP bypass.

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Evaluation of Estimates of Phosphorus Concentrations and Loadings from Ontario Municipal Wastewater Treatment Plants

1.) Introduction:

Many municipal wastewater treatment plants (WWTPs) in Ontario carry out chemical precipitation to remove phosphorus. Under the terms of the 1978 Great Lakes Water Quality Agreement between Canada and the United States, total effluent phosphorus concentrations for WWTPs treating wastewater in excess of one million gallons per day were limited to 1.0 mg/L assessed as an annual average. If the mean annual average concentration for effluent total phosphorus was less than 1.05 mg/L the WWTP has been judged to be in compliance (Monteith, 1988). Currently, as a result of a 1983 Supplemental Agreement between the two countries, compliance is assessed on a monthly basis.

In 1983, a supplement to the Great Lakes Water Quality Agreement set new target phosphorus loadings for the Great Lakes Basins. In response, the Ontario Ministry of the Environment (MOE) proposed to improve phosphorus removal at municipal WWTPs which are 1 MGD (4546 m3/d)or larger. Target phosphorus loading reductions for WWTPs were set at 30 tonnes per year for the Lake Erie Basin and 50 tonnes per year for the Lake Ontario/St. Lawrence Basin by the MOE. Based on 1983 WWTP flows, these target reductions would result in annual aggregate average phosphorus concentrations of 0.78 mg/L for WWTPs in the Lake Erie Basin and 0.91 mg/L in the Lake Ontario Basin.

Basin loads and annual aggregate phosphorus concentrations for municipal point sources in Ontario are estimates. They are calculated from data collected by operators at the 96 treatment WWTPs in the province with design capacities greater than 1 MGD (or 4546 m3/d). Data reported by operators are stored as monthly arithmetic averages in a computer database maintained by the Ontario Ministry of the Environment. For each WWTP, annual phosphorus loads are estimated as the product of the annual average phosphorus concentration and the total WWTP flow. The total load to each of the Great Lakes Basins is the sum of the loads for the individual WWTPs in that basin. As defined by the MOE, the "aggregate average phosphorus concentration" for a particular basin is the total basin loading divided by the total basin flow.

Table 1.1 provides a summary of the flows, phosphorus loadings, and aggregate average phosphorus concentrations for the three basins for the period 1981-1985. To serve as a comparison, the total estimated phosphorus loadings from both point and non-point sources were estimated to be 11,000 tonnes per year for the Lake Erie,7,000 tonnes per year for the Lake Ontario and 8,650 tonnes per year for the Upper Great Lakes Basins (Canviro,1988a).

The proposed target reductions in phosphorus loading of 50 tonnes/year for the Lake Ontario/ St. Lawrence Basin represented approximately 5% of the total basin loading from municipal WWTPs. For the Lake Erie Basin, the 30 tonnes per year reduction represented approximately 12% of the total basin loading from municipal point sources. Given that the total basin loadings and aggregate average phosphorus concentrations are estimates and not precise measurements, the following two questions are fundamental to the load reduction strategy proposed by the Ministry:

1.) Are the basin loading estimates for Lake Ontario and Lake Erie sufficiently precise to detect reductions of 50 tonnes per year from WWTPs in the Lake Ontario Basin and 30 tonnes per year in the Lake Erie Basin?

2.) What is the minimum reduction in phosphorus loading to each of the basins which can be detected?

Table 1.1:- Summary of Basin Flows, Loading, and Aggregate Average Phosphorus Concentrations (after Table 32, Canviro Consultants, 1988a).

BASIN	PARAMETER	1981	1982	1983	1984	1985
LAKE ERIE	Flow (1000 m3/d)	710.7	742.0	762.0	772.0	841.4
	Loading (tonnes/year)	229.4	250.7	246.9	222.6	247.1
	Agg. Avg. TP (mg/L)	0.90	0.93	0.89	0.79	0.80
LAKE ONTARIO/ ST. LAWRENCE	Flow (1000 m3/d)	2584.1	2654.0	2702.7	2687.6	2795.1
	Loading (tonnes/year)	1071.7	1026.6	949.5	979.1	950.1
	Agg. Avg. TP (mg/L)	1.14	1.06	0.96	1.00	0.93
UPPER GREAT LAKES	Flow (1000 m3/d)	342.5	369.3	373.2	385.9	416.6
	Loading (tonnes/year)	304.8	261.6	218.3	231.2	228.8
	Agg. Avg. TP (mg/L)	2.44	1.94	1.60	1.64	1.50

A study was undertaken to address these questions and provide information to assist in the development of future basin-wide management strategies for controlling phosphorus discharges from municipal sources. Specific objectives were as follows:

* to present an overview of current phosphorus removal practices at municipal WWTPs in Ontario;

* to assess how sampling methods (grab, composite, flow-weighted composite, etc.) affect daily phosphorus concentrations estimates;

* to summarize the statistical characteristics of effluent data from representative WWTPs;

* to compare different calculation techniques for estimating annual phosphorus loading from flow and effluent phosphorus concentration data reported by individual WWTPs in Ontario;

* to review the main technical issues influencing the selection of a statistic for reporting and assessing monthly compliance for phosphorus concentrations,

* to estimate the level of precision associated with estimates of basin phosphorus loadings and aggregate average phosphorus concentrations; in statistical terms, this is equivalent to establishing the 95% confidence limits for the basin load and aggregate annual concentration;

* to identify sources of imprecision and bias in the annual basin load and concentration estimates;

* to identify an appropriate sampling frequency for determining monthly phosphorus concentrations;

* to identify the implications of study results for the development of basin-wide phosphorus management strategies; and

* to provide recommendations for improving the management and analysis of data collected to control phosphorus mass discharges to the Great Lakes Basins.

This report summarizes the study methodology and results.

2.) Study Approach:

2.1) Sources of Data:

Three data sources were used for the study. For the 96 municipal WWTPs in Ontario larger than 4546 m^3/d, annual mean flow rates, effluent total phosphorus concentrations, and total phosphorus loadings for 1981-1985 were obtained from tables in "Phosphorus Removal Efficiency Upgrading at Wastewater Treatment Plants in the Great Lakes Basin, Phase 1, Historical Review" (Canviro, 1988b). Supplemental documentation (not presented in detail in the report) included sets of completed questionnaires summarizing interviews between the consultant conducting the study and WWTP operators concerning factors affecting phosphorus removal efficiency at the WWTPs. Attached to the questionnaires were tables of monthly averages of flow and total phosphorus concentration for each WWTP from the MOE database.

A second database was examined to establish how different types of samples (grab, composite, flow-weighted composite) influenced daily phosphorus concentration estimates. The data were obtained from an intensive sampling program at the Welland, Waterloo, and Galt WWTPs. Total and soluble phosphorus concentrations were obtained at two hour intervals for seven successive days.

To examine the performance of selected WWTPs, 1985 data were obtained from the MOE for three Metro Toronto WWTPs. Daily values for flow, effluent phosphorus concentration, effluent suspended solids, and daily phosphorus loading (the product of flow and phosphorus concentration) were logged into a minicomputer and their statistical properties examined.

2.2) Methodology:

2.2.1) Overview:- To provide an overview of the current status of phosphorus control practices in Ontario, long-term averages (1981-1985) for phosphorus concentrations and loads were entered in a Lotus spreadsheet for the 96 large municipal WWTPs. Distributions of total phosphorus loading and the number of WWTPs per basin were established for the Lake Erie, Lake Ontario/St. Lawrence, and Upper Great Lakes Basins. Numbers of WWTPs and percent loadings were classified according to type of treatment system (activated sludge, primary, etc.), type of chemical used for phosphorus removal, plant size, and sampling frequency.

2.2.2) Comparison of Sampling Methods:- Diurnal variations in flow rates and influent and effluent phosphorus concentrations at the Welland, Waterloo, and Galt WWTPs were examined by constructing time-series plots using "GRAFIT", a graphical software package. From the flow and grab phosphorus concentration values, mean daily phosphorus concentrations were calculated assuming volume and flow-weighted compositing over 8 and 24 hour periods. Mean values for the different compositing procedures were compared to the daily minimum and maximum grab sample concentrations.

2.2.3) Statistical Characteristics of Effluent Data:- To characterize the statistical nature of effluent data from municipal WWTPs, probability and time-series plots were prepared for the 1985 Metro Toronto data. Annual and monthly summary statistics were calculated for both the original and the log-transformed data using "STAT80", a statistical software package. Summary statistics included the mean, standard deviation, and coefficient of variation (the standard deviation divided by the mean).

To examine the degree of linear dependence between a set of variables, cross-correlation coefficients were calculated for daily effluent phosphorus and suspended solids concentrations, flows, and phosphorus loadings. The degree of correlation between values of the same variable at different times was examined by calculating sample autocorrelation coefficients using the "MITS" software package for time-series analysis.

2.2.4) Load Estimation Techniques:- The mass of effluent phosphorus discharged by a WWTP during a year is the area under the plot of instantaneous mass fluxes over the year:

$$L = \int L(t)\,dt = \int Q(t)*C(t)\,dt \quad \text{[2.1]}$$

where: L = the annual phosphorus load,
L(t) = the instantaneous phosphorus mass flux at time t
Q(t) = the instantaneous flow rate at time t,
C(t) = the instantaneous effluent phosphorus concentration at time t.

Municipal WWTPs do not sample and analyze for effluent phosphorus concentration on a continuous basis. Total phosphorus load must therefore be calculated based on available flow and phosphorus concentration data.

Currently, the annual total phosphorus load is calculated as the product of the arithmetic mean of the phosphorus concentration, the arithmetic mean of the flows and 365 (the number of days in the year). To determine if this procedure results in any bias in phosphorus load estimates, values from the current procedure for the three Metro Toronto WWTPs were compared to results from alternative estimation procedures. Results were compared on the basis of error, the difference between the phosphorus load estimate obtained by each method and the true load.

Comparisons were first made using complete WWTP records, consisting of 365 paired values of daily flow and effluent phosphorus concentrations. Secondly, simulations compared results assuming that the data records were incomplete, resulting from once per week sampling for effluent phosphorus (365 flow values but only 52 effluent phosphorus concentrations). The suitability of an estimation technique was judged on the basis of the errors for both cases.

2.2.5) Reporting and Assessing Monthly Compliance:- The main technical issues influencing the choice of a statistic for reporting and assessing monthly compliance were reviewed. Four statistics (the arithmetic mean, the flow-weighted mean, the geometric mean and the median) were evaluated in terms of: 1) their ability to reflect the nature of the distribution of effluent phosphorus concentration; 2) their sensitivity and accuracy in detecting violations; and 3) the resulting accuracy when used to calculate annual phosphorus loads.

A FORTRAN program was written to simulate the performance of the four statistics. From the 1985 data for one of the three Metro Toronto WWTPs, the program randomly selected one calendar month and calculated four summary statistics based on the data reported during the month. Values for the four statistics were also calculated when 1, 2, 4, 8, or 12 values were randomly selected from the month. Performance was evaluated by computing the differences between these latter values and the corresponding true value for the same statistic from the complete monthly data set. Results were also compared in terms of agreement with respect to compliance and the correlation coefficient between the value of the statistic at the low frequency and its true value.

2.2.6) Precision Estimates:- The precision of the mean phosphorus concentrations and annual load estimates was estimated for the three Metro Toronto WWTPs. The precision (or alternatively the uncertainty) of the estimates was quantified based on the 95% confidence interval for the mean of a sample, given as follows:

$$(\overline{x} - t_{a,n-1}*s/n^{1/2} < \mu < \overline{x} + t_{a,n-1}*s/n^{1/2}) \ldots\ldots\ldots\ldots\ldots\ldots [2.2]$$

where:
$\overline{x}$ = sample mean,
$s/n^{1/2}$ = the standard error of the mean
s = sample standard deviation,
n = number of samples,
μ = the population mean,
$t_{a,n-1}$ = value of t-statistic at α level of significance & n-1 degrees of freedom.

There is a 95% probability that the true mean is contained within the regions defined by the above equation (Reckhow and Chapra, 1983). Equation 2.2 is based on the assumption that the samples are selected randomly from a normal population.

Based on equation 2.2, Reckhow and Chapra (1983) developed a definition of precision as one-half of the width of the confidence interval for the mean as follows:

$$d = \mu - \overline{x} = t_{a,n-1} \cdot s/n^{1/2} \ldots\ldots\ldots\ldots\ldots\ldots [2.3]$$

Choosing the confidence interval at the 95% level and expressing the precision, d, as percent of the mean, results in the following relationship:

$$d\% = [d/\overline{x}]*100\% = [t_{a,n-1}*c.v./n^{1/2}]*100\% \ldots\ldots\ldots\ldots\ldots\ldots [2.4]$$

Equation 2.4 was adopted as the basic definition of precision throughout the study. For the three Metro Toronto WWTPs, precisions were computed for total phosphorus load and mean effluent phosphorus concentration on both an annual and monthly basis.

Short-term serial correlation (or autocorrelation) was observed in the daily effluent phosphorus concentrations and loads for all three Metro Toronto WWTPs. The presence of serial correlation, common in water quality data, invalidates a key assumption on which equation 2.2 is based, namely, the assumption of independence of samples (Sanders _et al_., 1987; Gilbert, 1987). Accordingly, the precision estimates for the three WWTPs were recalculated, correcting for serial correlation according to procedures given by Sanders _et al_. (1987) and Gilbert (1987). The precision estimates with and without correction for serial correlation were compared for the three selected WWTPs.

Based on procedures developed for the three Metro Toronto WWTPs, precisions were estimated for the phosphorus load and aggregate annual phosphorus concentrations (Table 1.1) for the Lake Erie and Lake Ontario Basins. Knowledge from the detailed statistical analysis of the Metro Toronto data was applied to other WWTPs for which detailed information was not available. Because the precision estimates depended on how the results from the three selected WWTPs were applied to other WWTPs in the basin, several different assumptions were made at each stage. This procedure--a type of sensitivity analysis--resulted in a range of precisions for basin loads and aggregate annual concentrations.

3.) Status of Phosphorus Control Practices in Ontario:

3.1) WWTP Performance and Distribution of Basin Loads:

From information summarized by Canviro Consultants (1988a), tables were developed listing the type of treatment system and the chemical used for phosphorus removal for the 96 municipal WWTPs in Ontario which treated flows in excess of 4546 m^3/d. In addition, the tables (Appendix A.1), contain the long-term (1981-1985) averages for daily flow, phosphorus concentration, phosphorus load, and sampling frequency.

Using the information in Appendix A.1, the number of WWTPs and the percentage of total basin phosphorus loading from municipal sources were classified in each of the three basins according to treatment system, WWTP capacity, the chemical used for phosphorus removal, and the frequency of effluent sampling. The classification system for WWTP capacity was loosely based on a scheme contained in the National Inventory of Municipal Waterworks and Wastewater Systems in Canada (Federation of Associations on the Canadian Environment, 1981). The classes and designations are as follows:

WWTP Flows (10^3 m^3/d)		WWTP Capacity	
> 400:		Very Large (VL)	
400-40:	400-200:	Large (L):	L3
	200-100:		L2
	100-40:		L1
40-4.5:	40-20:	Medium (M):	M3
	20-10:		M2
	10-4.5:		M1
< 4.5:		Small (S)	

Distributions of the total number of WWTPs and the total phosphorus loading per basin were summarized in a series of plots (Fig. 3.1 to 3.4). In addition, for all Ontario WWTPs which had capacities greater than 4546 m^3/d, a summary (Table 3.1) was prepared of the average annual effluent phosphorus concentrations for 1984 and 1985 according to treatment system (primary, secondary, and secondary with effluent filtration). Table 3.2 lists the number of WWTPs in each of the three basins which collected fewer than one or two effluent samples per week for phosphorus analysis.

3.2) Overview of Control Practices:

3.2.1) Process Status:- Table 3.1 shows that both primary and secondary WWTPs in Ontario practising chemical addition achieved annual effluent phosphorus concentrations less than 1.0 mg/L, on average, in 1984 and 1985. For both years, the average annual effluent concentration for primary WWTPs with chemical addition was approximately 0.1 mg/L more than that from secondary WWTPs with chemical addition. During the same period, WWTPs in Ontario with effluent filtration achieved annual effluent phosphorus concentrations in the 0.6-0.7 mg/L range, values which were on average 0.1 to 0.3 mg/L lower than concentrations from WWTPs with chemical addition but without effluent filtration. WWTPs without chemical addition had effluent concentrations which exceeded 1.3 mg/L in both years.

3.2.2) Basin Status:- Based on the information in Fig. 3.1-3.4 and Table 3.2, an overview of the status of phosphorus removal for the WWTPs in each of the three basins is given as follows:

Lake Erie Basin:

In contrast to the other two basins, there was a more uniform distribution of the total phosphorus loading among the 31 municipal WWTPs in the Lake Erie Basin. The three

Figure 3.1:- Classification Of Percentage of Basin Phosphorus Load by Treatment System.

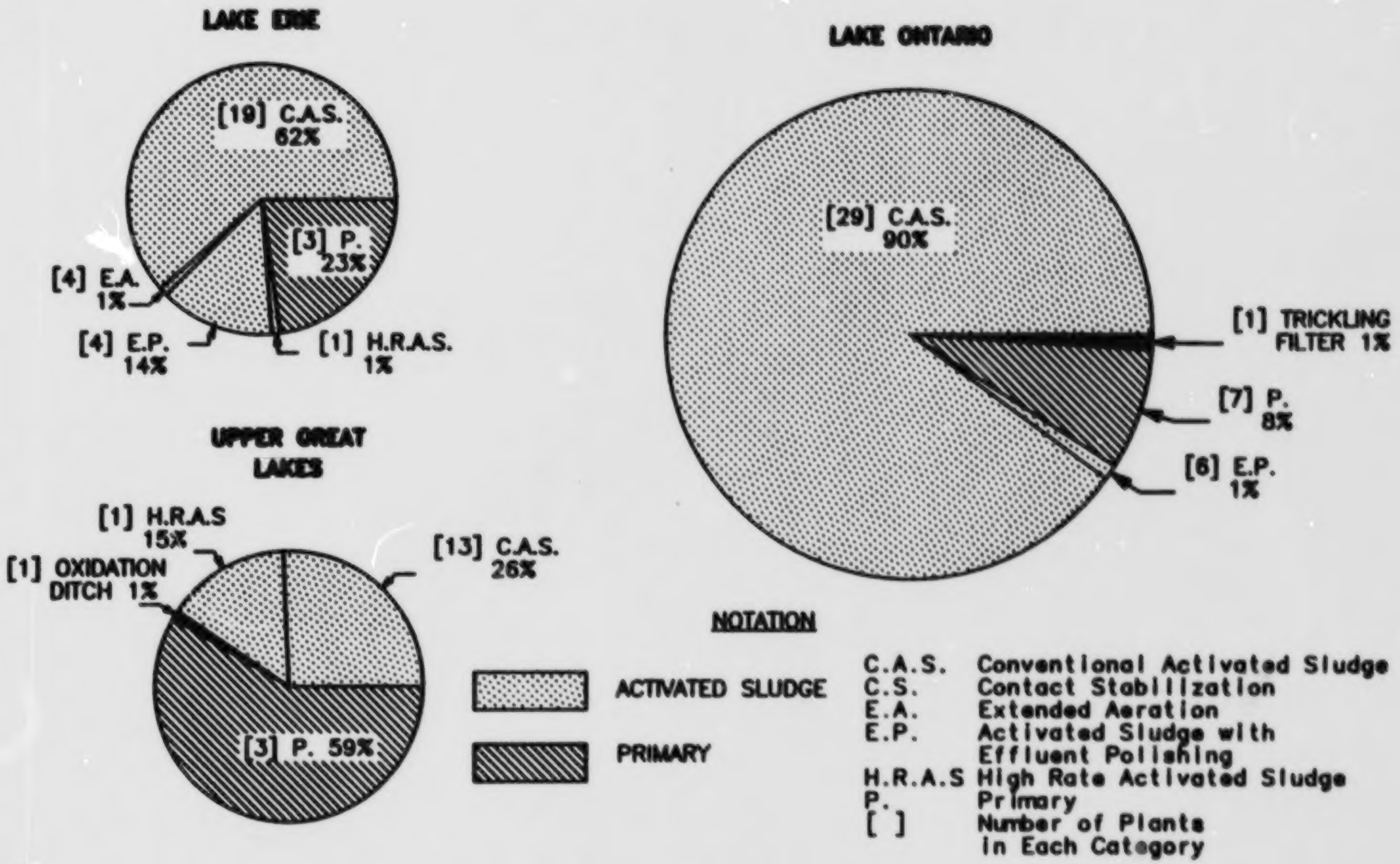


Figure 3.2:- Classification of Percentage of Basin Phosphorus Load by WWTP Capacity.

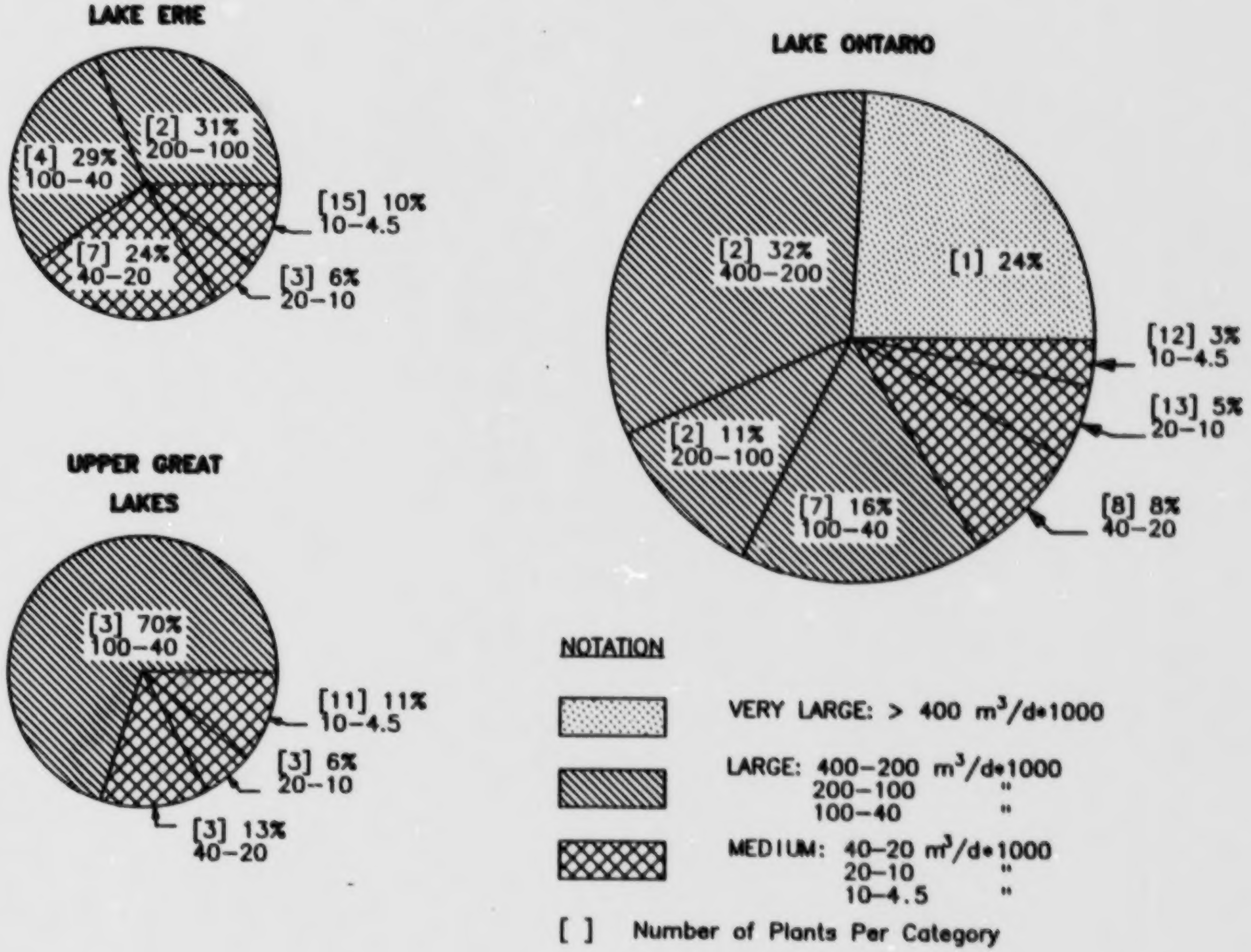


Figure 3.3:- Classification of Percentage of Basin Phosphorus Load by Chemical Type.

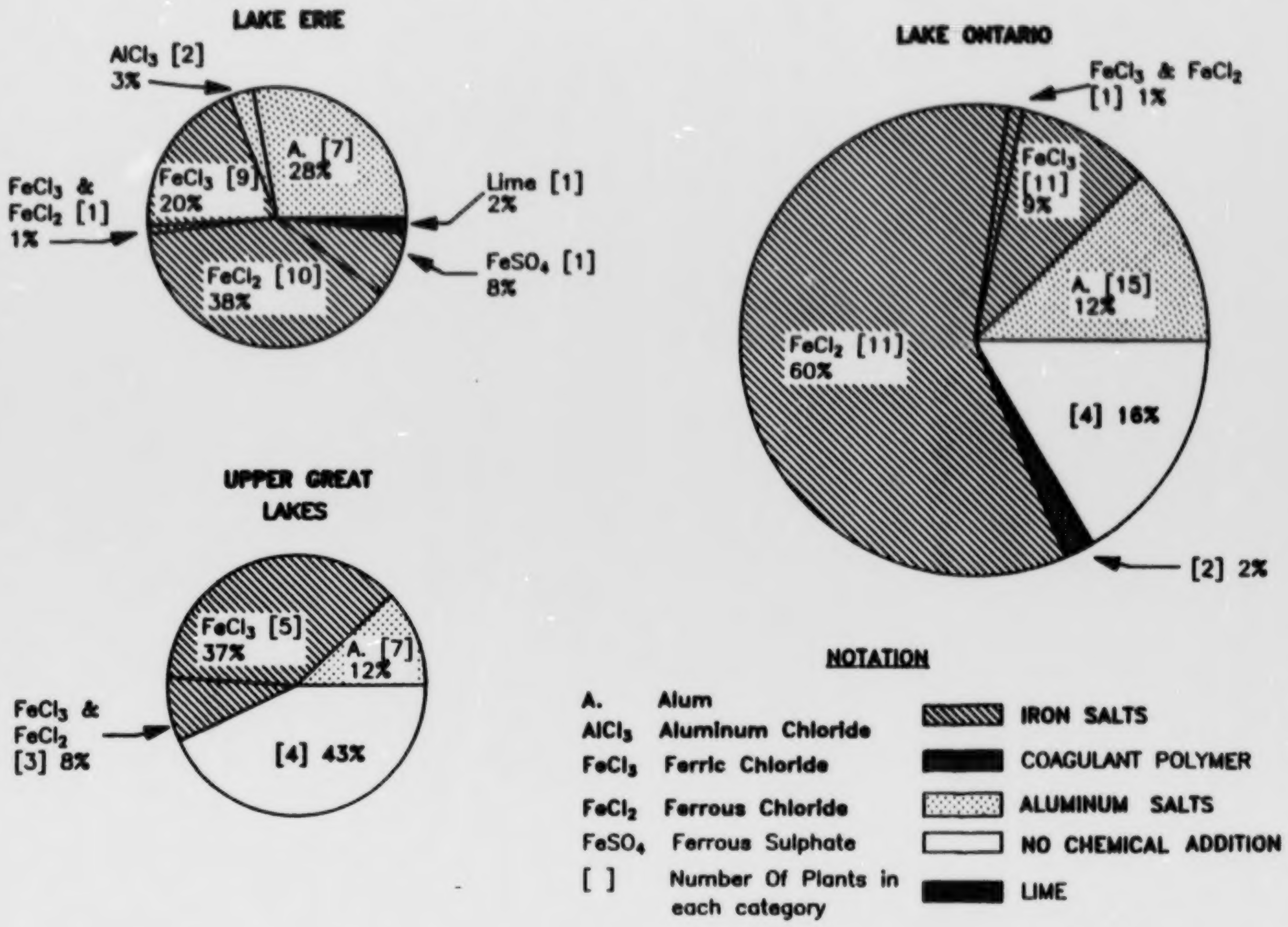


Figure 3.4:- Classification of Percentage of Basin Phosphorus Load by Sampling Frequency.

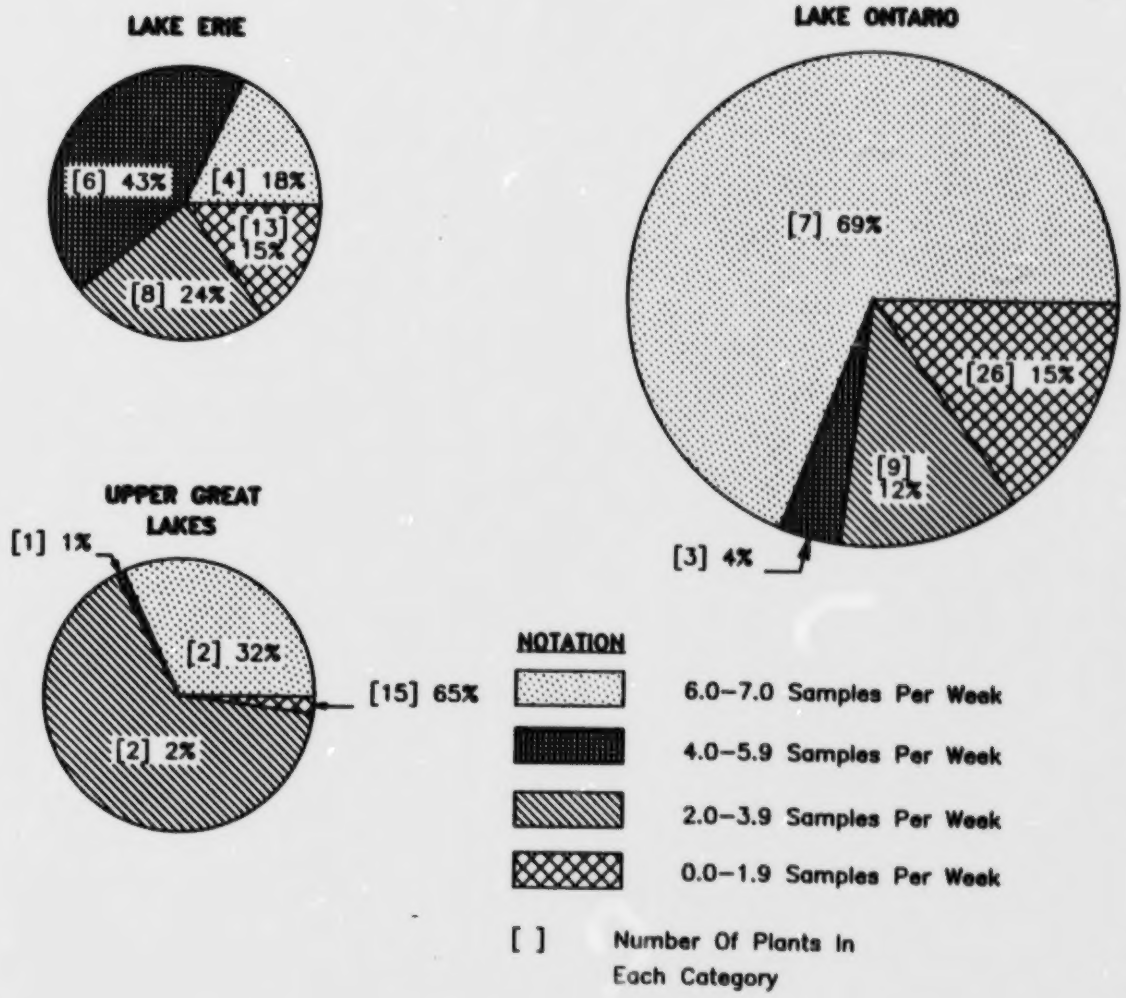


Table 3.1:- Average Performance of Different Types of WWTPs in Ontario.

Plant Class:	Chemical Addition:	No. of Plants:	Avg. Agg. TP Conc. (1984)	Avg. Agg. TP Conc. (1985)
Primary:	Yes	11	0.97	0.90
	No	1	4.74	4.01
Secondary:	Yes	65	0.88	0.80
	No	7	1.31	1.47
Effluent Filtration:	Yes	10	0.71	0.55

Table 3.2:- Number of Ontario WWTPs sampling Less than or Equal to Once or Twice Per Week.

PLANT SIZE: (m3/d*1000)	LAKE ERIE		LAKE ONTARIO		UPPER GREAT LAKES	
	LE 2	LE 1	LE 2	LE 1	LE 2	LE 1
1.) VERY LARGE (>400)	--	--	--	--	--	--
2.) LARGE:						
L3: 400-200	--	--	--	--	--	--
L2: 200-100	--	--	--	--	--	--
L1: 100-40	--	--	3	2	2	1
3.) MEDIUM:						
M3: 40-20	3	2	3	1	2	2
M2: 20-10			9	3	1	1
M1:10-4.5	10	9	10	8	10	9
Total number of plants	13	11	25	14	15	13

LE: Less than or equal to

largest contributors in the basin--the Greenway (London), Westerly (Windsor), and Guelph treatment WWTPs--accounted for 39% of the approximately 250 tonnes per year discharged to Lake Erie from municipal WWTPs. Nineteen out of the 31 WWTPs were conventional activated sludge WWTPs accounting for 62% of the total loading from all WWTPs. Three WWTPs [the Westerly (Windsor), Sarnia, and Amhertsburg WWTPs] did not have secondary treatment. Four WWTPs in the basin carried out effluent polishing following activated sludge treatment.

All WWTPs in the basin practised chemical addition for phosphorus removal. Because they are less costly, iron salts were preferred to aluminum salts. Ferrous chloride was the most common type of coagulant for phosphorus removal.

Sixty-one percent of the total basin phosphorus loading originated from WWTPs which sampled 4 times per week or more. None of the WWTPs which were classified as large, treating flows in excess of $40*10^3$ m^3/d, sampled less frequently than twice per week.

Lake Ontario/St. Lawrence River Basin:

Ninety percent of the total phosphorus loading from the 45 municipal WWTPs in the Lake Ontario Basin was discharged from conventional activated sludge WWTPs. Relatively few WWTPs in the basin dominated the phosphorus loading from municipal sources. The Metro Toronto (Main), Hamilton (Woodward Ave.) and Metro Toronto (Humber) WWTPs, the three largest in the basin, accounted for 56% of the approximately 1000 tonnes per year discharged to Lake Ontario from municipal WWTPs. One of these WWTPs, the Hamilton (Woodward Ave) WWTP, did not add coagulant for phosphorus removal. The Main WWTP, by far the largest in the province, accounted for approximately one-quarter of the total municipal loading to the Lake Ontario Basin.

Seven WWTPs which accounted for 7.6% of the phosphorus load did not have secondary treatment. These included Cornwall, Niagara Falls (Stamford), Brockville, Kingston City, Fort Erie (Anger Ave.), Iroquois, and Prescott-Edwardsburg. [Since the compilation of the 1985 data, Niagara Falls (Stamford) has installed secondary treatment using rotating biological contactors (RBCs)]. Accounting for this change, 6.1% of municipal load originated from WWTPs without secondary treatment.

The majority of WWTPs in the basin practised chemical addition using iron salts. Ferric chloride was the most popular iron salt.

Seventy-three percent of the total basin phosphorus load was discharged by WWTPs which sampled 4 times or more per week. However, three of the WWTPs classified as large (Burlington, Kingston, and Peterborough) sampled twice per week or less.

Upper Great Lakes Basin:

The Upper Great Lakes Basin contained the least number of WWTPs (20 in total) of the three basins. Three WWTPs (Thunder Bay, Sudbury, and Sault Ste. Marie) classified as large accounted for 70% of the total phosphorus loading from Ontario municipal WWTPs in the Upper Great Lakes. Two of these WWTPs [Sault Ste. Marie (old) and Sudbury] did not practice chemical addition at the time the report was prepared. Three WWTPs in the basin--Sault Ste. Marie (old), Thunder Bay, and Owen Sound--provided primary treatment only. Forty-three percent of the total basin phosphorus loading came from WWTPs without chemical addition for phosphorus removal. Iron salts were the most popular coagulant. Both the Sault Ste. Marie (old) and the Sudbury WWTPs sampled for effluent phosphorus less than twice per week.

4.) Comparison of Sampling Methods:

Flow and phosphorus concentration data from an intensive sampling program were analyzed to determine how different sampling methods affected mean daily phosphorus concentrations. Grab samples of influent and effluent were collected at two hour intervals (2:00,4:00,..,24:00) at the Welland, Waterloo and Galt WWTPs for the periods listed in Table 4.1. Flow rates were recorded at the time of sample collection to determine the flow in each two hour interval. Samples were analyzed for total and soluble phosphorus concentrations. Sampling was carried out as part of a study to investigate the dynamic variability of trace contaminants in activated sludge WWTP influents and effluents (Canviro, 1988e).

Values for the different compositing procedures were based on calculations from the flows and grab sample concentrations and not from side-by-side collection of both grab and composites samples. Consequently, actual composite sampling may introduce additional variability above that associated with the calculated composites.

4.1) Background:

Table 4.2 provides background information concerning the performance of the Welland, Waterloo, and Galt WWTPs. The three WWTPs operated below their design flow rates. Total effluent phosphorus concentrations averaged less than 1.0 mg/L for the period 1981-85. With the exception of the Welland WWTP which discharged an annual average total effluent phosphorus concentration of 1.10 mg/L in 1982, the WWTPs were in compliance for the period 1981-1985. The Galt WWTP had just switched to ferrous chloride prior to the intensive sampling program.

Table 4.1:- Duration of Intensive Sampling Program at Three WWTPs.

PLANT:	Start of 2-h Sampling Date:	Start of 2-h Sampling Time:	Completion of 2-h Sampling Date:	Completion of 2-h Sampling Time:	No. of Complete Days
Welland	19/8/86	8:00	27/8/86	12:00	7
Waterloo	2/7/86	12:00	10/7/86	16:00	7
Galt (Cambridge)	30/9/86	8:00	8/10/86	12:00	7

Table 4.2:- Background Statistics on Three WWTPs Subjected to Intensive Sampling.

PLANT/BASIN:	DESIGN FLOW (1000 m3/d)	CHEMICAL ADDED:	1981-85 AVER.: FLOW: (1000 m3/d)	1981-85 AVER.: P CONC. (mg/L)
Welland [Lake Ontario]	69.0	ferrous chloride	38.3	0.69
Waterloo [Lake Erie]	45.5	ferrous chloride	39.3	0.81
Galt (Cambridge) [Lake Erie]	38.6	ferric chloride	31.6	0.86

4.2) Data Plots:

Time-series plots, Figs. 4.1-4.3, were constructed for flows and grab sample concentrations for the seven-day sampling period. In addition, ratios of the hourly averages to the grand average (the average of all grab sample concentrations) were plotted against the hour, Fig. 4.4. The hourly average for 8:00, for instance, is the average for the values at 8:00 across eight days of the intensive sampling program. Values for effluent concentration at Welland on day 6-7 and those at Waterloo on day 5-6 were not included in the hourly averages because they contained excursions which did not conform to the overall pattern of the other days. In Fig. 4.4, ratios greater than 1.0 indicate hourly averages greater than the overall average; conversely, ratios less than 1.0 indicate hourly averages less than the overall average. The greater the departure from 1.0, the greater the departure from the overall mean.

The performance of the three WWTPs varied considerably during the intensive sampling period. For the Welland WWTP, the total effluent phosphorus concentrations averaged 0.96 mg/L over the intensive sampling period, with soluble effluent phosphorus averaging 0.60 mg/L. Soluble phosphorus concentrations increased above 1.0 mg/L on day 6 indicating that the rate of chemical addition had decreased for a short period. At the Waterloo WWTP, concentrations averaged 1.2 mg/L for total phosphorus and 0.66 mg/L for soluble phosphorus. A major excursion in total and soluble effluent phosphorus concentration can be observed in Fig. 4.2, starting on day 4. For approximately 36 hours soluble phosphorus concentrations were 1.0 mg/L or greater suggesting that the rate of chemical addition at the WWTP was inadequate.

Figure 4.1:- Time Plots for Flow and Influent and Effluent Phosphorus Concentrations for the Welland WWTP.

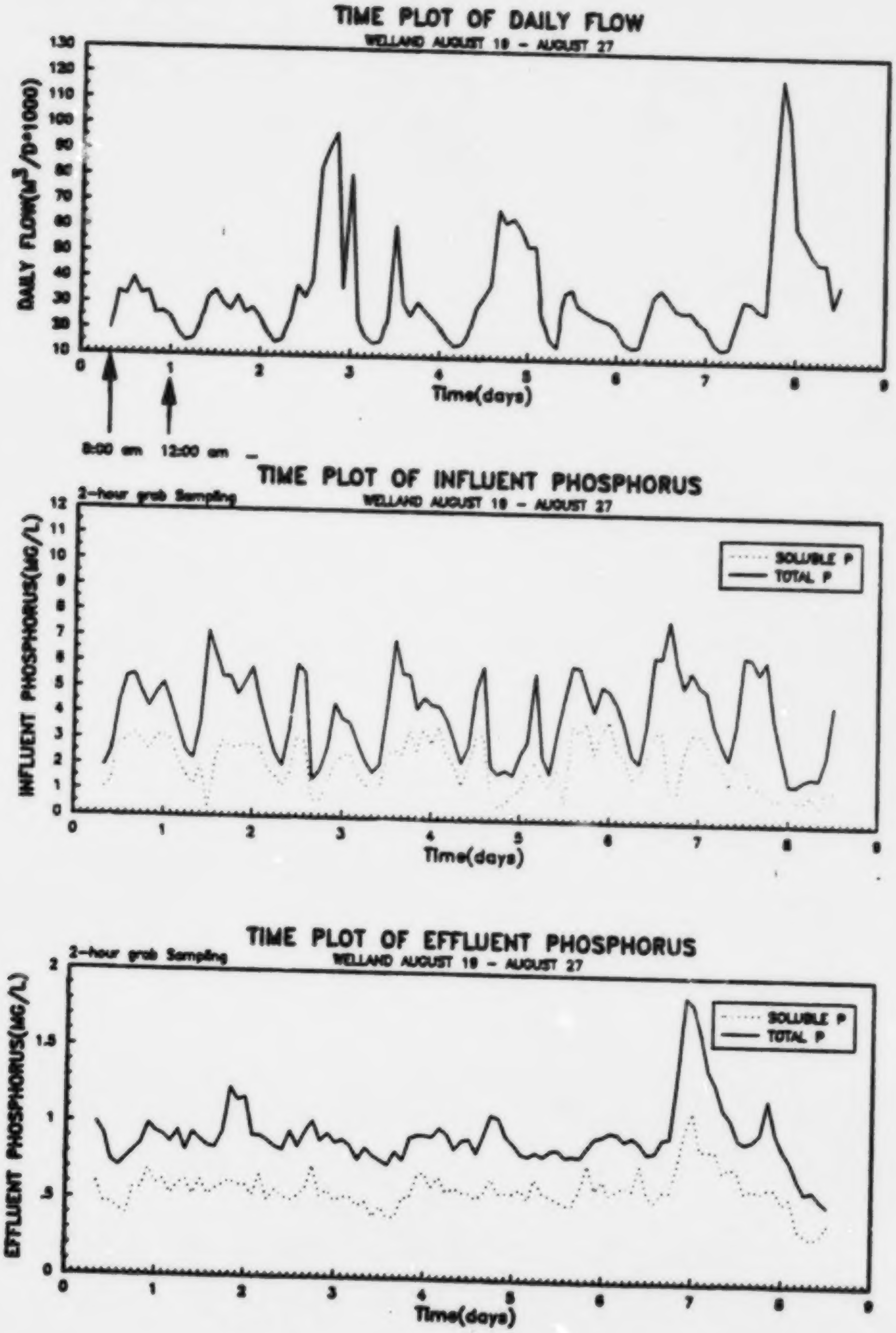


Figure 4.2:- Time Plots for Flow and Influent and Effluent Phosphorus Concentrations for the Waterloo WWTP.

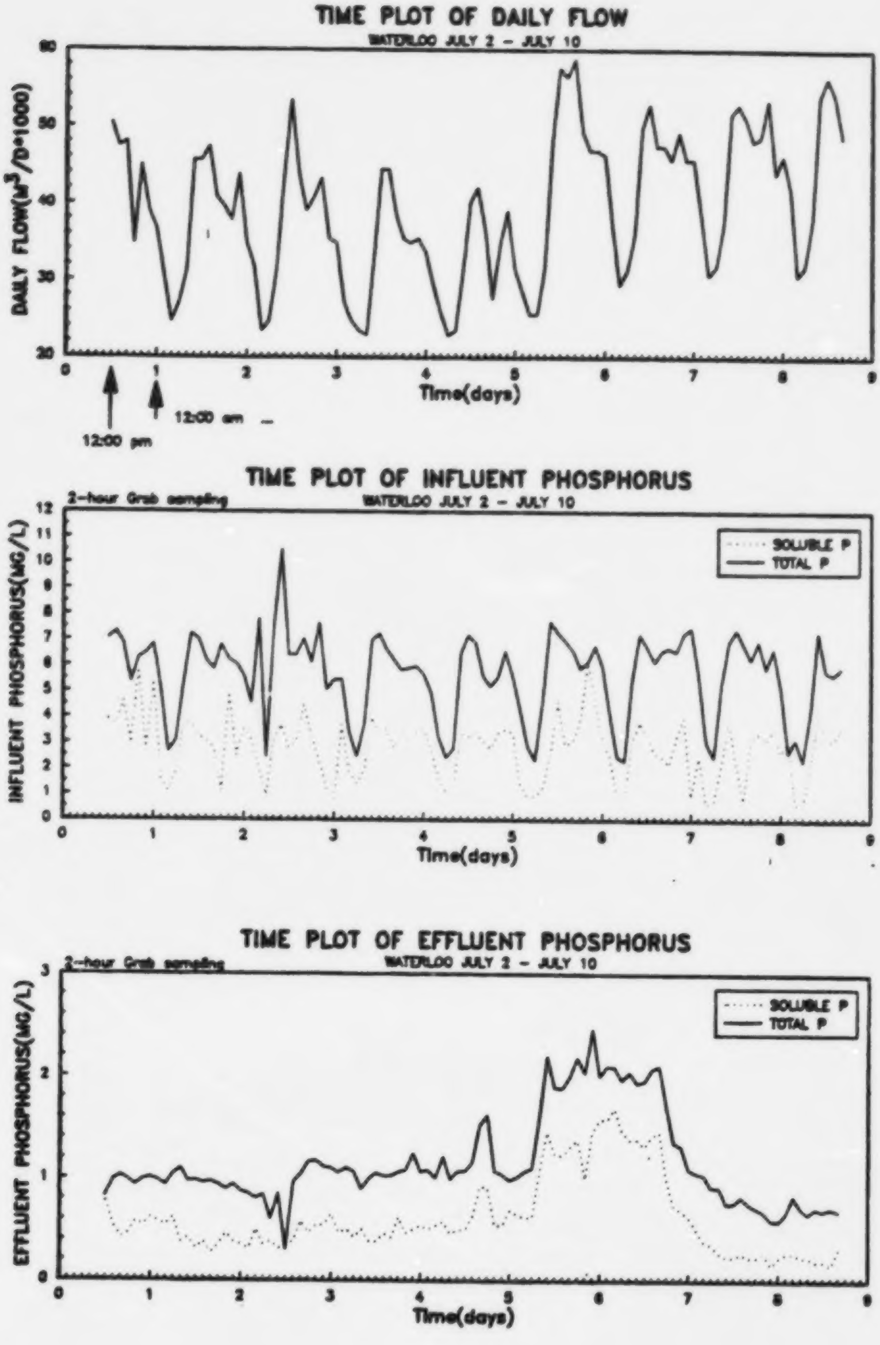


Figure 4.3:- Time Plots for Flow and Influent and Effluent Phosphorus Concentrations for the Galt WWTP.

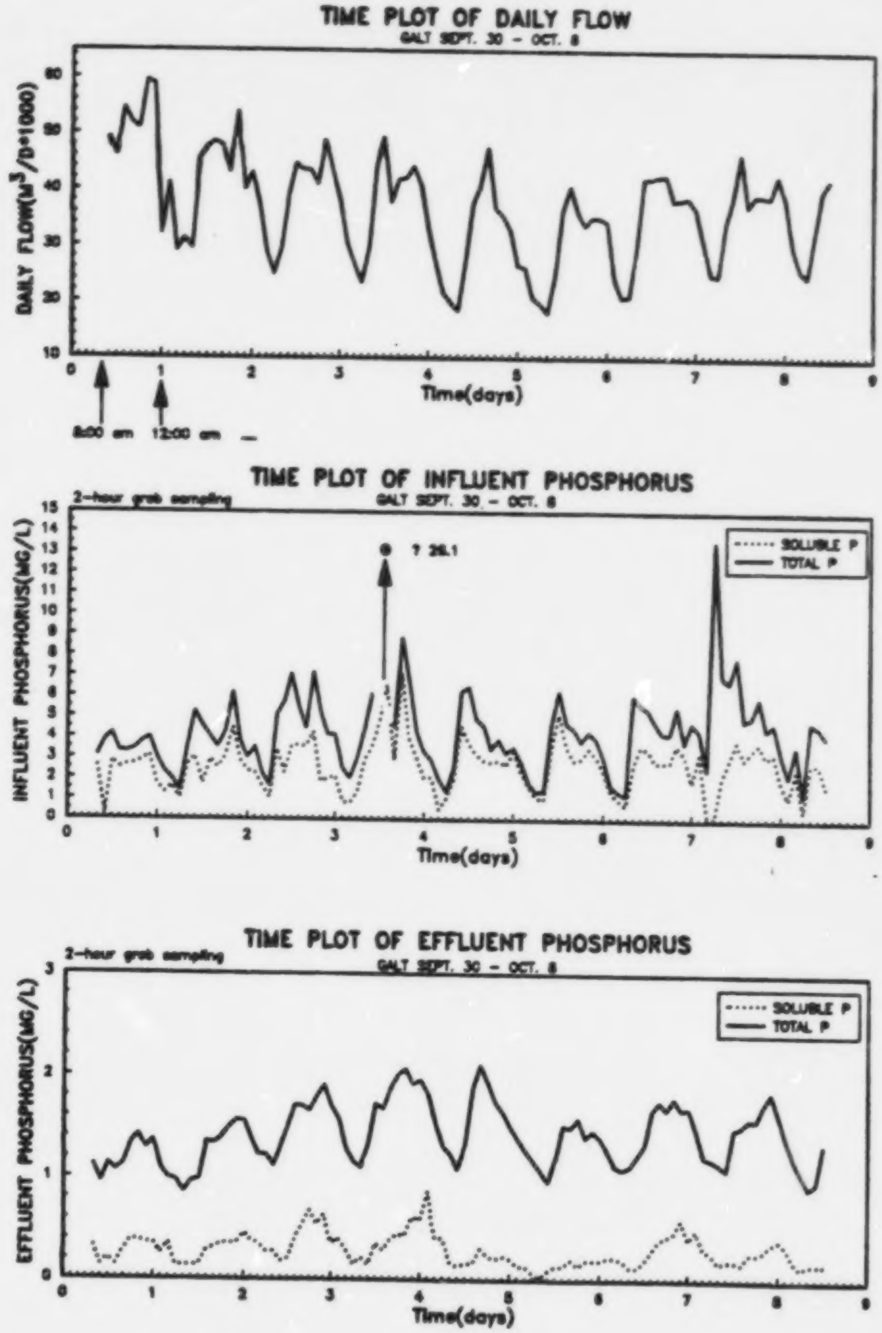
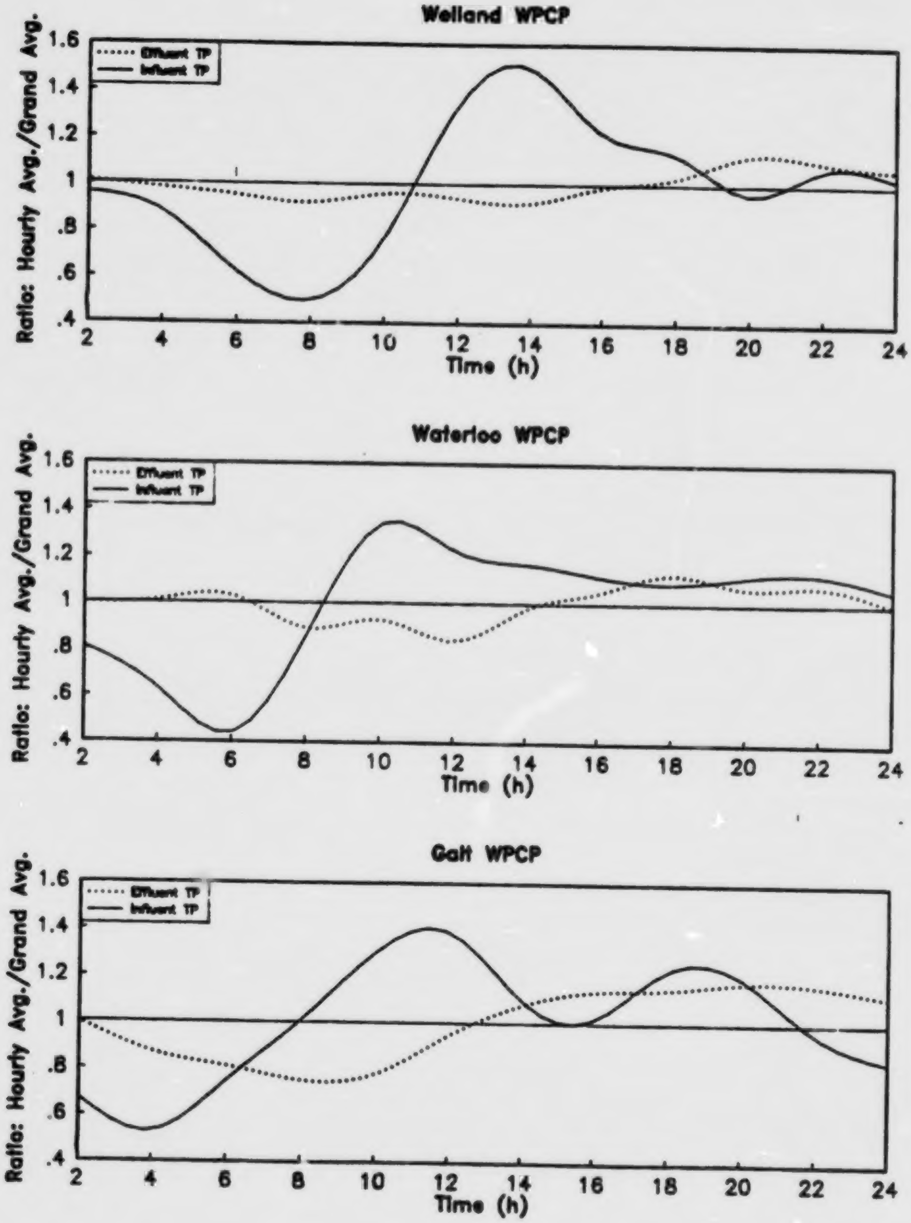


Figure 4.4:- Average Hourly Influent and Effluent Phosphorus Concentrations Variations at Three WWTPs.



The Galt WWTP had the highest effluent total phosphorus concentration, 1.5 mg/L, of the three WWTPs intensively monitored. However, soluble effluent phosphorus concentrations were low, 0.30 mg/L on average. It appears, therefore, that chemical addition was adequate at the Galt WWTP during the sampling period and that the majority of effluent phosphorus was particulate and, as such, was not amenable to removal through chemical addition.

Figs. 4.1-4.3 display the presence of strong diurnal fluctuations in influent total and soluble phosphorus concentrations at the three WWTPs. Minimum influent total phosphorus concentrations typically occurred in the early morning, 4:00-8:00 (Fig. 4.4). Influent total phosphorus concentrations peaked in the late morning or early afternoon, between 10:00-14:00. For the Welland and Waterloo WWTPs, the strong diurnal fluctuations in influent phosphorus concentrations were largely damped out by the time they reached the effluent (Figs. 4.1, 4.2, & 4.4). In contrast, for the Galt WWTP diurnal fluctuations occurred in effluent total phosphorus concentration (Figs. 4.3 & 4.4). The minimum and maximum effluent total phosphorus concentrations at the Galt WWTP occurred 6-8 hours later than the corresponding minimum and maximum values in influent phosphorus concentrations.

4.3) Sampling Method Calculations:

Using the flow and grab sample concentrations, mean daily phosphorus concentrations were compared for different sampling methods. Daily means assuming equal volume composites were calculated as the arithmetic average of the grab sample values. Means based on flow-weighted composites were calculated as the product of the flow and the concentration divided by the sum of the flows. Equal volume and flow-weighted composites were calculated on an 8-hour (8:00-16:00) and 24-hour basis. Seven sets of mean phosphorus concentrations, corresponding to each day with a complete set of 2-h samples, were calculated for each of the three WWTPs.

Appendix A.2 contains tables listing daily means for the four sample types (24-hour flow-weighted composites, 8-h flow weighted composites, 24-h equal volume composites and 8-h equal volume composites) for the three WWTPs. In addition, the tables list the daily maximum and minimum grab sample concentrations with associated time of collection. Tables 4.3 and 4.4 summarize the results, averaged over the seven days with complete 2-h samples. The differences listed in Tables 4.3 and 4.4 were obtained by comparing the results from a sampling method and those from the 24-h flow-weighted mean and expressed as a percentage of the 24-h flow-weighted mean. Estimates based on 24-h flow-weighted composites were judged to be the most accurate.

Because of the presence of strong diurnal fluctuations in influent soluble and total phosphorus at all three WWTPs, the 8-h composites (either equal volume or flow-weighted composites) underestimated the mean daily influent phosphorus concentration by 15%-20%, on average, in comparison to values from 24-h flow-weighted composites (Table 4.3). In contrast, differences between 24-h equal volume and flow-weighted composites averaged less than 5%.

For the Welland and Waterloo WWTPs, there was little difference (2% or less) between values for any of the sampling methods for effluent phosphorus. In contrast, for the Galt WWTP, differences in mean daily effluent concentrations ranged between 17-20% for 8-h volume and flow-weighted composite samples in comparison to 24-h flow-weighted composite samples. At the Galt WWTP, there was little difference (3% or less) between 24-hour

Table 4.3:- Comparison of Results for 2-h Influent Data for Welland, Waterloo, and Galt WWTPs.

Plant:	Parameter	Flow-weighted Comp		Volume Composite		Grab Samples	
		24 h	8 h	24h	8h	Max.	Min.
Infl. TP:							
Welland	Average	4.16	3.25	4.17	3.24	6.64	1.84
	%Diff		-22%	0%	-22%	60%	-56%
Waterloo	Average	5.93	5.02	5.67	4.70	7.81	2.42
	%Diff		-15%	-4%	-21%	32%	-59%
Galt	Average	4.80	3.87	4.59	3.67	10.28	1.65
	%Diff		-19%	-4%	-24%	114%	-66%
	Avg %Diff		-19%	-3%	-22%	68%	-60%
Infl. Sol. P:							
Welland	Average	2.05	2.02	2.18	2.02	3.45	0.73
	%Diff		-1%	6%	-1%	68%	-64%
Waterloo	Average	2.82	2.33	2.69	2.16	4.42	0.97
	%Diff		-17%	-5%	-23%	57%	-66%
Galt	Average	2.88	2.09	2.71	1.94	4.75	0.75
	%Diff		-27%	-6%	-33%	65%	-74%
	Avg %Diff		-15%	-1%	-19%	63%	-68%

Table 4.4:- Comparison of Results for 2-h Effluent Data for Welland, Waterloo, and Galt WWTPs.

Plant:	Parameter	Flow-weighted Comp 24 h	Flow-weighted Comp 8 h	Volume Composite 24h	Volume Composite 8h	Grab Samples Max.	Grab Samples Min.
Effl. TP:							
Welland	Average	0.96	0.94	0.96	0.95	1.25	0.82
	%Diff		-2%	0%	-1%	30%	-15%
Waterloo	Average	1.21	1.19	1.21	1.18	1.53	0.82
	%Diff		-2%	0%	-2%	26%	-32%
Galt	Average	1.50	1.22	1.46	1.22	1.84	1.05
	%Diff		-19%	-3%	-19%	23%	-30%
	Avg %Diff		-7%	-1%	-7%	26%	-26%
Effl. Sol. P:							
Welland	Average	0.60	0.61	0.61	0.61	0.79	0.50
	%Diff		2%	2%	2%	32%	-17%
Waterloo	Average	0.66	0.66	0.65	0.65	0.94	0.40
	%Diff		0%	-2%	-2%	42%	-39%
Galt	Average	0.30	0.24	0.30	0.25	0.56	0.13
	%Diff		-20%	0%	-17%	87%	-57%
	Avg %Diff		-6%	0%	-6%	54%	-38%

equal volume and flow-weighted composites. Grab samples of soluble effluent phosphorus ranged from 43% to 187% of corresponding 24-h flow-weighted composites. These large differences suggest that difficulties may be encountered in some cases if operators attempt to control the rate of chemical dosage for phosphorus removal based on the results of an individual daily grab sample.

5.) Statistical Characteristics of Effluent Data:

5.1) Background:

To obtain an understanding of the statistical characteristics of long-term effluent data from municipal WWTPs practising phosphorus removal, data from three representative WWTPs were analyzed in detail. The data consisted of daily values for 1985 for total flow, total effluent phosphorus concentration, and total effluent suspended solids concentration for the Main, Humber, and Highland Creek WWTPs in Toronto.

These WWTPs were selected because they had nearly complete records for 1985. Secondly, being activated sludge WWTPs which use iron salts for phosphorus removal, they were representative of the type of treatment system which accounted for the majority of phosphorus load discharged into the Lake Erie and Lake Ontario Basins from municipal sources (see Figs. 3.1 & 3.3). In addition, as previously discussed, because the Main WWTP discharges approximately 25% of the total phosphorus load from municipal sources to Lake Ontario, its performance requires special attention.

Table 5.1 provides a summary of the long-term performance of the three WWTPs. All the WWTPs were operating below their design flows. Annual averages for flow and total effluent phosphorus concentration for the period from 1981-1985 are summarized in Table 5.2. Basing compliance on an annual effluent phosphorus concentration of less than 1.05 mg/L, the Main WWTP was out of compliance one year in five, the Humber WWTP four years in five, and the Highland Creek WWTP one year in five. Table 5.2 shows that the Main annual phosphorus concentrations increased over the five year period.

Table 5.1:- Background Statistics on Three Metro Toronto WWTPs.

PLANT:	DESIGN FLOW (1000 m3/d)	CHEMICAL ADDED:	1981-85 AVER.:	
			FLOW: (1000 m3/d)	P CONC. (mg/L)
Main (Metro Toronto)	818.3	ferrous chloride	743.0	0.93
Humber (Metro Toronto)	409.1	ferrous chloride	371.6	1.26
Highland Creek (Metro Toronto)	218.2	ferrous chloride	159.7	0.95

Table 5.2:- Historical Flows & Effluent Phosphorus Concentrations for Three Metro Toronto WWTPs.

YEAR:	MAIN		HUMBER:		HIGHLAND CREEK:	
	FLOW: (1000 m3/d)	P CONC. (mg/L)	FLOW: (1000 m3/d)	P CONC. (mg/L)	FLOW: (1000 m3/d)	P CONC. (mg/L)
1981	752.4	0.80	406.0	1.50	153.2	1.00
1982	709.2	0.91	368.7	1.24	162.3	1.04
1983	737.6	0.89	365.5	1.04	162.8	1.05
1984	677.3	0.97	339.6	1.43	156.9	0.91
1985	838.3	1.09	378.1	1.08	163.3	0.77
81-85 MEAN:	743.0	0.93	371.6	1.26	159.7	0.95
81-85 s:	54.1	0.10	21.4	0.18	4.0	0.11

s: standard deviation of the mean

5.2) Data Plots:

Using 1985 values for daily flow and total effluent phosphorus concentration, daily phosphorus load in kilograms per day was calculated as the product of the two values when both were recorded on a given day. Values for the three parameters (flow, phosphorus concentration and phosphorus load) were examined by constructing time-series plots (Fig. 5.1-5.3). The plots for the effluent data for the Main WWTP, Fig. 5.1, show that there were large excursions in total phosphorus concentration and load in five months (February, May, June, October, and November). Excursions in February, March, and November correspond to peaks in daily flow. However, the largest peak in total phosphorus concentration and load occurred in October and did not correspond to a peak in flow.

The effluent data plots for the Humber and Highland Creek WWTPs (Figs. 5.2 & 5.3) show that their effluent phosphorus variability was less than that for the Main WWTP. In addition, none of the excursions in total phosphorus load or concentration corresponded to peaks in daily flow. For all three WWTPs the shape of the phosphorus loading plot more closely resembled the shape of the total effluent phosphorus plot than the daily flow plot, indicating that phosphorus loading is more closely correlated with concentration than with flow.

Probability plots for flows, effluent phosphorus concentration and effluent suspended solids are given in Appendix A.3 for the three WWTPs. With the exception of daily flows for the Highland Creek WWTP which were normally distributed, the bulk of the data in the plots were log-normally distributed. In the case of the probability plots for the Main WWTP, there were significant departures from log-normality. Low and high values on the plots bent away from a central linear portion demonstrating that the effluent data distribution had longer tails than the log-normal distribution. The observed

Figure 5.1:- Time Series Plots of 1985 Main Data

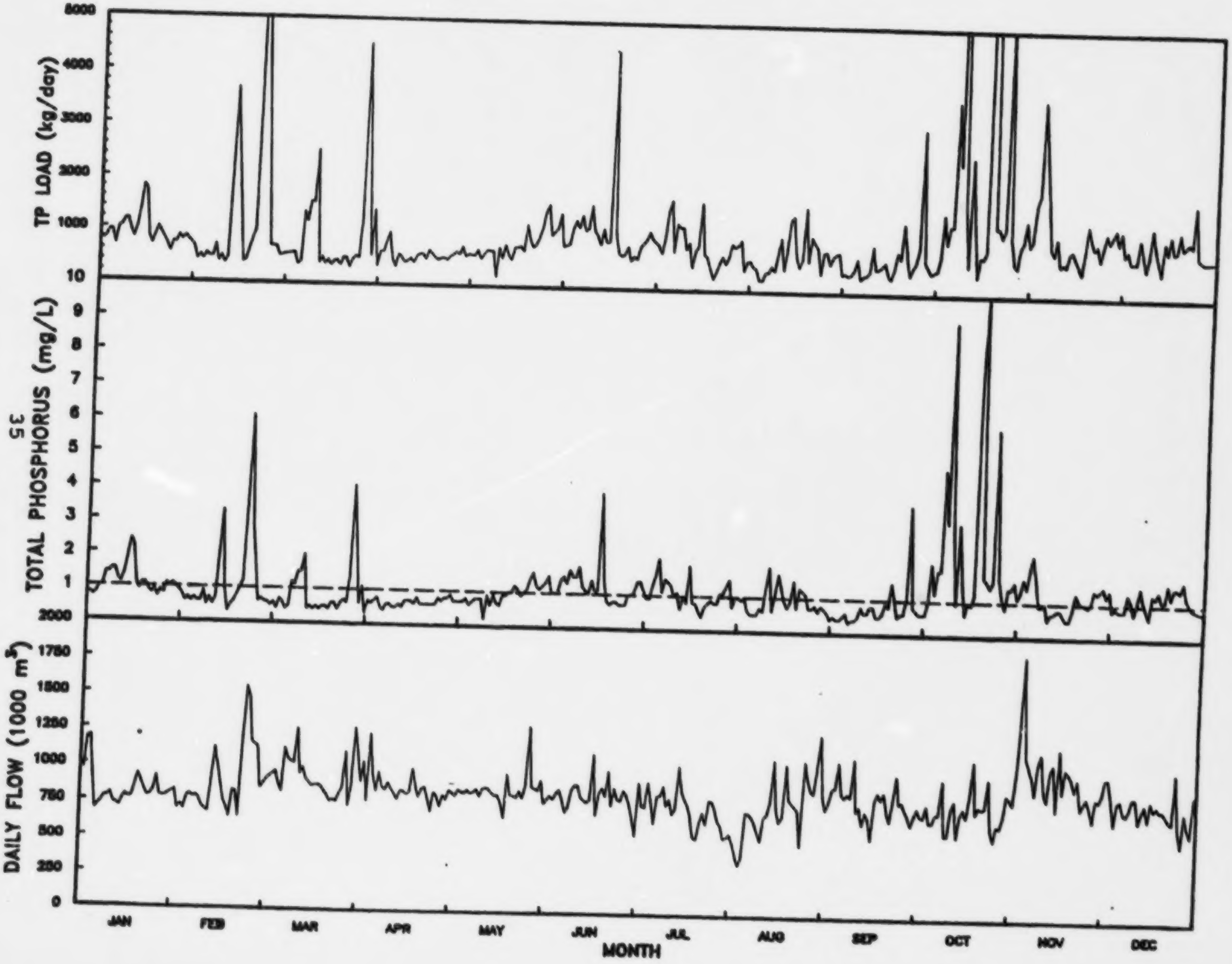


Figure 5.2:- Time Series Plots of 1985 Humber Data.

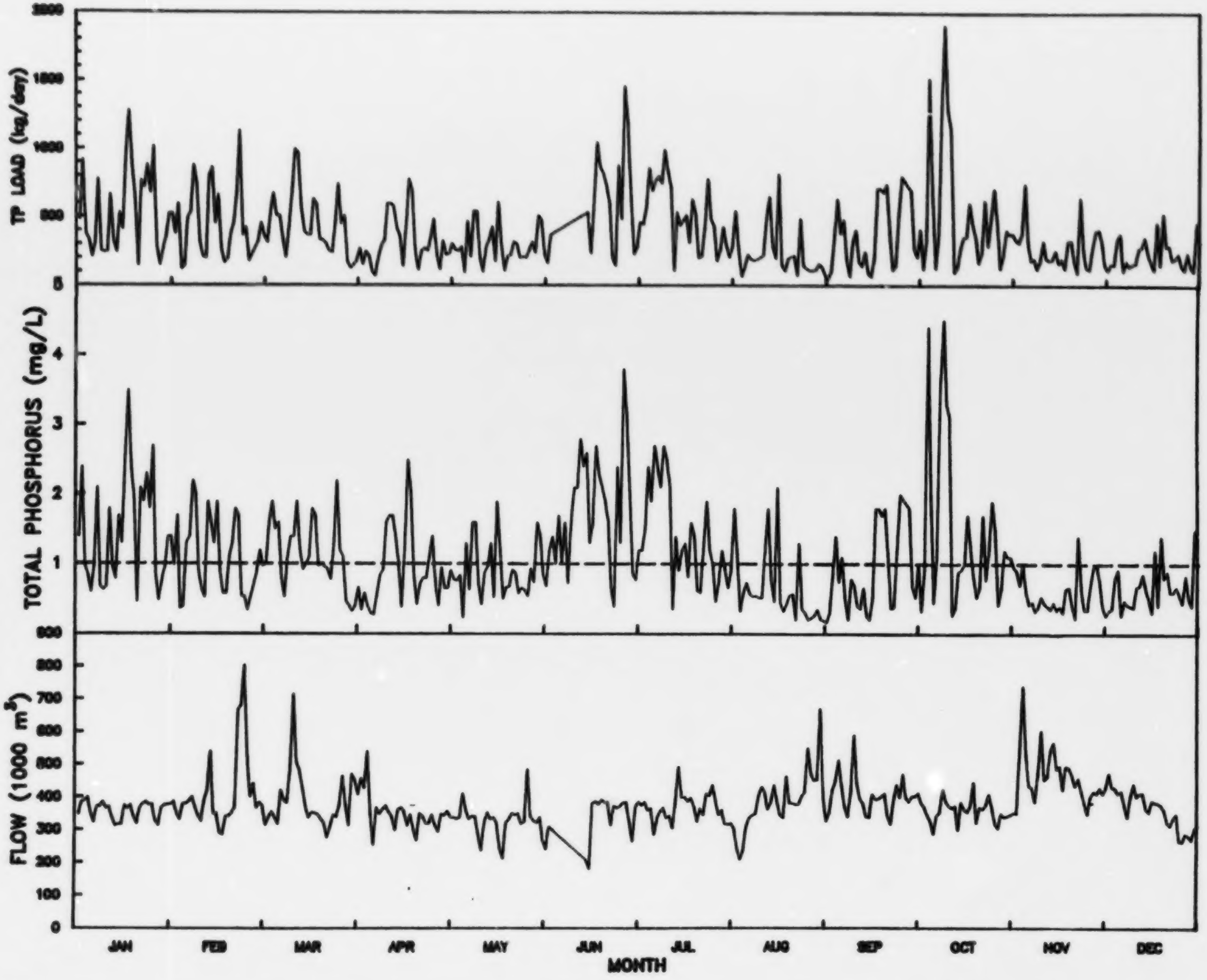
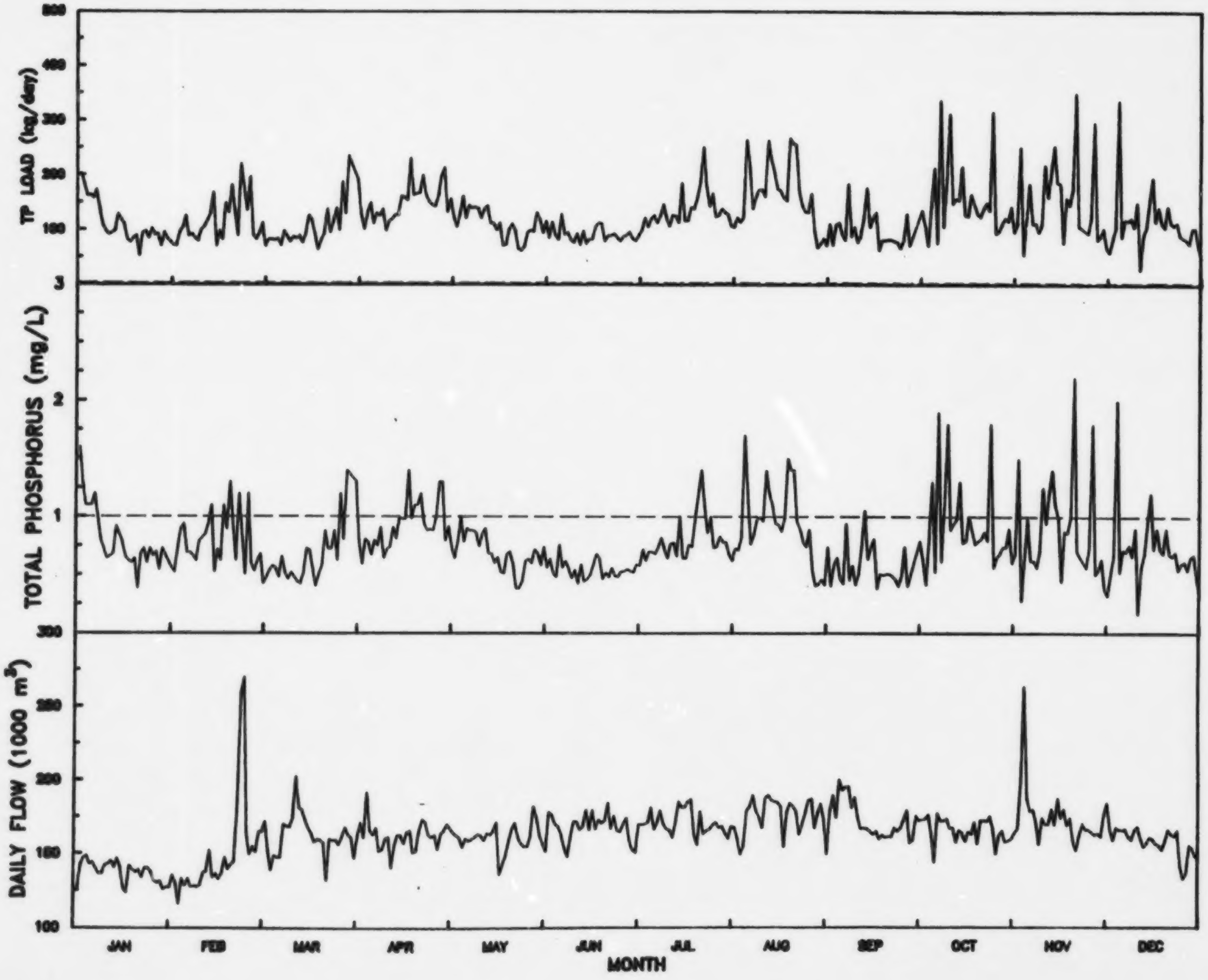


Figure 5.3:- Time Series Plots of 1985 Highland Creek Data.



distribution contained values which were more extreme than those predicted by the log-normal distribution. The probability distributions for the Main effluent data appear to be a mixture of two distributions--one distribution corresponding to normal operation and a second corresponding to upset conditions.

5.3) Summary Statistics:

5.3.1) Raw Data:-

Values for means, standard deviations and coefficients of variation (c.v) were calculated on an annual basis and presented in Table 5.3. The coefficient of variation (c.v.) was calculated as:

$$c.v = s/\bar{x} \quad [5.1]$$

where: s = the standard deviation,

$\bar{x}$ = the mean.

The mean daily flow for the Main WWTP was approximately double the Humber WWTP and four times the Highland Creek WWTP. Flow variability as characterized by the annual coefficient of variability was similar for Main and Humber but smaller for Highland Creek. The mean phosphorus concentrations for the Main and Humber WWTPs exceeded the effluent compliance level of 1.0 mg/L. The Highland Creek WWTP was well below the compliance level. Variabilities in phosphorus concentration, phosphorus loading, and suspended solids were greatest for Main and least for Highland Creek.

Means, standard deviations and coefficients of variation were also calculated on a monthly basis for each of the three WWTPs and presented in Appendix A.4. For all three WWTPs, the highest coefficient of variation for flow was for the month of February, indicating that conditions were the most changeable for this month. Low flow months were June for Main and Humber and

Table 5.3: 1985 Annual Summary Statistics for Main, Humber and Highland Creek WWTPs.

Parameter	Mean:	Std. dev.	C.V.	N
MAIN:				
Flow (1000 m3/d)	838.3	165.3	0.20	348
Total P Conc. (mg/L)	1.12	1.02	0.91	348
Total Sus. Solids (mg/L)	26.6	42.2	1.59	348
Total P Load (kg/d)	983.4	1083.6	1.10	333
HUMBER:				
Flow (1000 m3/d)	378.6	75.6	0.20	354
Total P Conc. (mg/L)	1.07	0.72	0.67	361
Total Sus. Solids (mg/L)	18.1	10.8	0.60	360
Total P Load (kg/d)	393.8	273.9	0.70	350
HIGHLAND CREEK:				
Flow (1000 m3/d)	163.3	17.8	0.11	365
Total P Conc. (mg/L)	0.77	0.29	0.38	354
Total Sus. Solids (mg/L)	16.2	10.5	0.65	349
Total P Load (kg/d)	124.6	50.1	0.40	354

C.V. = coefficient of variation
N = number of values contained in annual data set.

January for Highland Creek; high flow months were November (Main and Humber) and August (Highland Creek).

For the Main WWTP mean effluent phosphorus concentrations were greater than 1.0 mg/L for 7 of out the 12 months. For the month of October concentrations were unusually high, averaging 2.5 mg/L. Excluding October, monthly means ranged from 0.63 (April) to 1.24 (June). For Humber, 6 months had monthly mean phosphorus concentrations which exceeded 1.0 mg/L. The means ranged from 0.58 (November) to 1.73 (June). At Highland Creek no monthly mean phosphorus concentration exceeded 1.0 mg/L. The means ranged from 0.55 (June) to 0.93 (April). For all three WWTPs the month with the highest coefficient of variation for total phosphorus load was also the month with the highest coefficient of variation for total phosphorus concentration. Variability of effluent phosphorus concentration was least for Highland Creek and greatest for Main.

5.3.2) Log-Transformed Data:-

The probability plots indicated that most of the distributions were more nearly log-normally than normally distributed. Therefore, summary statistics were calculated for the log-transformed data. Values were calculated for the geometric mean (x_g) and the dispersion factor (D.F.), defined by Sachs (1984) in the following manner:

$$\bar{x}_g = 10^{\bar{x}_L} \quad \text{..} [5.2]$$

$$\text{D.F.} = 10^{s_L} \quad \text{..} [5.3]$$

where: $\bar{x}_L$ = the mean of the $\log_{10}$ transformed data,

s_L = the standard deviation of the $\log_{10}$ transformed data.

The results, calculated on an annual basis, are presented in Table 5.4. Appendix A.4 summarizes the results calculated on a monthly basis.

For the Main and Humber WWTPs, the geometric mean is approximately 0.2 mg/L smaller than the equivalent arithmetic mean, indicating that the effluent phosphorus concentrations for these WWTPs are highly skewed. For the Highland Creek WWTP, there is little difference between the annual geometric mean and the arithmetic mean of the effluent phosphorus concentrations.

For both the Main and Humber WWTPs, monthly geometric means were greater than 1.0 mg/L for 5 of out the 12 months. As was the case for the arithmetic means, Highland Creek had no months during the year when the geometric means exceeded 1.0 mg/L. Months with the highest arithmetic means also had the highest geometric means.

5.4) Cross-Correlations:

To further examine the relationship between the data variables, correlation coefficients were generated based on analysis of the daily values. A correlation coefficient is a measure of the linear relationship between two variables. It equals zero if there is no linear relationship. The more closely the correlation coefficient equals ± 1.0, the greater the linear dependence between the two variables. The correlation coefficients were tested for significance against zero at the 5% level (Sachs, 1984). Only three values, marked in Table 5.5, were not significant.

As shown by the values for the correlation coefficient in Table 5.5, phosphorus loading is highly correlated to phosphorus concentration but poorly correlated to flow, as noted in Section 5.2. Main has the highest degree of correlation of all three WWTPs between flow and effluent suspended solids concentration and between effluent suspended solids concentration and effluent phosphorus concentration. This suggests that at Main the discharge of suspended solids during high flow periods is, in part, responsible for high levels of phosphorus.

Table 5.4: 1985 Annual Geometric Mean Statistics for Main, Humber and Highland Creek WWTPs.

Parameter	Geometric Mean:	Dispersion Factor:	N:
MAIN:			
Flow (1000 m3/d)	823.3	1.21	348
Total P Conc. (mg/L)	0.93	1.71	348
Total Sus. Solids (mg/L)	17.6	2.18	348
Total P Load (kg/d)	778.6	1.81	333
HUMBER:			
Flow (1000 m3/d)	371.9	1.2	354
Total P Conc. (mg/L)	0.87	1.95	361
Total Sus. Solids (mg/L)	14.9	1.98	360
Total P Load (kg/d)	316.7	1.95	350
HIGHLAND CREEK:			
Flow (1000 m3/d)	162.4	1.11	365
Total P Conc. (mg/L)	0.72	1.42	354
Total Sus. Solids (mg/L)	14.1	1.63	349
Total P Load (kg/d)	116.4	1.44	354

Table 5.5: Correlation Coefficients for 1985 Data for Main, Humber and Highland Creek WWTPs.

Parameter	Flow:	TP Conc.:	TSS:	TP Load:
MAIN:				
Flow	-	0.18	0.23	0.37
Total P Conc.		-	0.89	0.97
TSS			-	0.89
TP Load				-
HUMBER:				
Flow	-	-0.10 *	-0.13	0.13
Total P Conc.		-	0.53	0.96
TSS			-	0.49
TP Load				-
HIGHLAND CREEK:				
Flow	-	-0.01 *	0.03 *	0.24
Total P Conc.		-	0.42	0.96
TSS			-	0.40
TP Load				-

*:- These values tested as not significant at the 5% confidence level for a two-tailed test.

5.5) Serial Correlation:

Serial correlation in a data set arises when values close together in time tend to be correlated; a value greater than a long-term mean tends to be followed by a second value which is also greater than the mean (Chatfield, 1984). To determine if serial correlation was present in the data from the three selected WWTPs, sample autocorrelation coefficients (r_k) were calculated at several different lags (k) for daily effluent phosphorus concentrations and loads. Sample autocorrelation coefficients were computed according to:

$$r_k = \Sigma(x_t - \overline{x})*(x_{t+k} - \overline{x}) \ / \ \Sigma(x_t - \overline{x})^2 \text{.................} [5.4]$$

Values of r_k, given in the above equation, are simply the correlation coefficients for x regressed against itself at various lags (k).

Missing values in each of the Metro Toronto data sets presented a problem in calculating the sample autocorrelation coefficients. For the effluent phosphorus concentrations, 1-5% of the daily values were missing and for the phosphorus loads 4-9% were missing. To address the problem autocorrelations were estimated by excluding those terms which contained missing values from the sum of products (the numerator) and the sum of squares (the denominator) in equation 5.4. The approach is described in detail by Cryer (1986).

The results, listed in Table 5.6, and the correlograms (plots of r_k versus lag k) provided in Appendix A.5, demonstrate that daily phosphorus loads and flows were serially correlated. Values of the lag 1 autocorrelation coefficients in Table 5.6 were compared to WWTP variabilities listed in Tables 5.3 and 5.4 to determine if the two were inversely related--the lower the variability, the higher of the value of the lag 1 autocorrelation

Table 5.6:- Lag 1 Autocorrelation Coefficients: Daily Effluent Phosphorus Concentrations and Loads for Three Metro Toronto WWTPs.

Data Set:	Main	Humber	Highland Creek
Daily Effluent Phosphorus Concentrations	0.46	0.56	0.36
Daily Effluent Phosphorus Loads	0.38	0.53	0.38

coefficient. However, no such relationship was apparent from the results for the three Metro Toronto WWTPs.

The presence of serial correlation has several important consequences. Correlated observations contain less information than the same number of independent observations. To illustrate this, a set of n samples which are serially correlated is sometimes expressed in terms of an effective sample size, n_e, the number of independent samples with the same information content (Reckhow and Chapra, 1983). For a first-order model of time-dependence, effective sample size is given by (Reckhow and Chapra, 1983):

$$n_e=n*(1-r_1)/(1+r_1) \quad \ldots\ldots [5.5]$$

Based on the above equation, the information content of a complete annual data set with 365 values and lag 1 sample autocorrelation coefficients of 0.4, 0.5, and 0.6 (the range of values for the three Metro Toronto WWTPs) is the equivalent of a random series containing 157, 120 and 91 values respectively. Further, because precision (equation 2.4) is defined on the basis of the number of independent samples, the effects of serial correlation must be taken into account or precision will be over-estimated.

6.) Load Estimation Techniques:

Techniques were assessed for calculating annual phosphorus loads using the 1985 data for the Main, Humber, and Highland Creek WWTPs. Results were compared on the basis of error, the difference between the phosphorus load estimate obtained by each method and the true load.

Errors for the load estimation techniques were compared, firstly, for complete annual data records consisting of 365 paired values of daily flow and effluent phosphorus concentrations. In addition, because many WWTPs in Ontario do not conduct daily sampling for effluent phosphorus, simulations were conducted to compare results assuming once per week sampling, the annual record consisting of 365 daily flow values but only 52 total effluent phosphorus concentration values. The accuracy of an estimation technique was judged on the basis of the resulting errors for both cases.

Section 6.1 presents a description of the load estimation techniques. Methodology and results are presented in Section 6.2 for complete annual data records and in Section 6.3 for records based on weekly sampling.

6.1) Description of Estimation Techniques:

Equations for each of the techniques are listed in Table 6.1 and comments are provided as follows:

Method #1 (Mean annual Q,C):- The annual phosphorus load for a WWTP is calculated as the product of the daily means for flow rate and total effluent phosphorus concentration and 365 (the number of days in a year). The means are based on all values reported by the WWTPs during the year. Currently, the Ontario Ministry of the Environment uses this technique for estimating yearly phosphorus loading into the Great Lakes Basin from

Table 6.1 Equations for Calculating Annual Phosphorus Loads

Method #1: Mean annual Q,C

$$L(1) = 365 * \bar{Q} * \bar{C} \quad \text{.................................} [6.1]$$

where: $\bar{Q}$ = mean daily flow rate,

$= [\sum_{i=1}^{n} Q_i]/n$

Q_i = daily flow rate,

n = number of days in year with flow records,

$\bar{C}$ = mean daily total effluent phosphorus concentration,

$= [\sum_{i=1}^{m} C_i]/m$

C_i = daily total effluent phosphorus concentrations,

m = number of days in year with phosphorus concentration records.

Method #2: Mean annual Q,C_f

$$L(2) = 365 * \bar{Q} * \bar{C}_f \quad \text{.................................} [6.2]$$

where: $\bar{C}_f$ = flow-weighted annual mean total phosphorus concentration.

$= [\sum_{i=1}^{p} L_i]/[\sum_{i=1}^{p} Q_i]$

L_i = daily phosphorus loadings = $Q_i * C_i$,

p = number of days in year with both flow and phosphorus concentration records,

$Q_i, \bar{Q}$ = as previously defined.

Method #3: Mean annual L

$$L(3) = 365*\bar{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [6.3]$$

where: $\bar{L}$ = mean daily phosphorus flux

$$= \sum_{i=1}^{p} (L_i)/p$$

L_i, p = as previously defined.

Method #4: Mean monthly Q,C

$$L(4) = \sum_{i=1}^{12} (ni*\bar{Q}_i*\bar{C}_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [6.4]$$

where: $\bar{Q}_i$ = mean daily flow for month i,

$\bar{C}_i$ = mean daily TP concentration for month i,

n_i = number of days per month, month i,

Method #5: Mean monthly Q, C_f

$$L(5) = \sum_{i=1}^{12} (ni*\bar{Q}i*\bar{C}_{f}i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [6.5]$$

where: $\bar{C}_{f}i$ = flow-weighted mean daily TP concentration for month i,

$$= [\sum_{i=1}^{q} L_i]/[\sum_{i=1}^{q} Q_i]$$

q = number of days in month i with both flow and phosphorus concentration records,

Q_i, n_i, L_i = as previously defined.

Method #6: Mean Monthly Q, C_g

$$L(6) = \sum_{i=1}^{12} (ni*\bar{Q}_i*\bar{C}_{g}i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [6.6]$$

where: $\bar{C}_{g}i$ = geometric mean daily TP concentration for month i,

Q_i, n_i = as previously defined.

municipal sources. The technique is simple to use and, in contrast to some other load estimation techniques, makes use of all the available data. The method uses the mean daily flow rate as an estimate of missing flows and the mean daily phosphorus concentration as an estimate of missing concentrations.

Method #2 (Mean annual Q,C_f):- The calculation is similar to Method #1, except that the flow-weighted mean daily phosphorus concentration replaces the arithmetic daily mean phosphorus concentration. The method improves the accuracy of load estimates in comparison to Method #1 when flows are correlated to phosphorus concentrations. The method uses the mean daily flow rate as an estimate of missing flows and the mean daily flow-weighted phosphorus concentration as an estimate of missing concentrations.

Method #3 (Mean annual L):- Daily loading rates are calculated as the product of the daily flow and the daily effluent phosphorus concentration. If one or both of the values is missing for a given day, then loading rate (or phosphorus mass flux) cannot be calculated for that day. The total yearly load is the product of the mean daily arithmetic loading rate and 365. The method estimates missing daily loads by the mean daily loading rate calculated for all of the days in the year when both flow and effluent phosphorus concentrations were reported.

Method #4 (Mean monthly Q,C):- This method is also similar to Method #1, except that the calculations are carried out on a monthly instead of annual basis. The monthly load is obtained as the product of the mean daily flow (based on the values reported in the month), the mean daily total phosphorus concentration (based on the values reported in the month), and the number of days in the month. The total phosphorus load for each WWTP is the sum of the individual monthly loads. The method uses the mean daily flow rates and phosphorus concentrations, calculated on a monthly basis, as estimates of missing flows and concentrations in the month. Method #4 could easily be implemented as WWTPs in Ontario currently report mean flows and effluent concentrations on a monthly basis.

Method #5 (Mean monthly Q, C_f):- The annual load is the sum of twelve monthly loads based on the mean daily flow rate and the flow-weighted mean daily total effluent phosphorus concentration.

Method #6 (Mean monthly Q, C_g):- The same basic calculation procedure is employed as for the previous two procedures, except that the daily geometric mean phosphorus concentration is used in place of either the arithmetic or flow-weighted mean. Although Method #6 clearly underestimates annual loads, it was included in the analysis because preliminary consideration was being given by the MOE to defining monthly compliance limits based on geometric mean daily phosphorus concentrations and an estimate was required of the size of the error in annual load estimates. The method uses the mean daily flow rates and the geometric mean concentrations, calculated on a monthly basis, as estimates of missing flows and concentrations in the month.

6.2) Comparison of Results: Complete Data Record

Initially, results from the different load calculations were compared assuming that a WWTP had a complete data record corresponding to 365 paired flow and effluent phosphorus concentrations values. However, for 1985 there were 17 flow and effluent phosphorus values missing for Main, 11 flow and 4 phosphorus values missing for Humber, and 11 phosphorus values missing for Highland Creek. To provide complete data records, estimates of the missing values were obtained using first-order linear interpolation (Press et al., 1986). The algorithm is as follows:

$$Y_{est} = Y_1 + (t - t_1)(Y_2 - Y_1)/(t_2 - t_1) \quad ....[6.7]$$

where:

Y_{est} = estimate for missing value (flow or effluent phosphorus concentration) at day t;

Y_1 = measured value in the previous record at day t_1;

Y_2 = measured value in the next record at day t_2.

For the complete data sets for the three WWTPs, the "true loads" were calculated as the sum of the products of the daily flow and phosphorus concentrations (Richards and Holloway, 1987). The error for each method was then the difference between the load calculated by the estimation technique (Table 6.1) and the true load. Errors were expressed as a percentage of the true load. Table 6.2 summarizes the results.

In comparison to Method #1 (mean annual Q,C) which is currently used to calculate annual load, three calculation techniques (#2, #3, and #5) were more accurate and two (#4 and #6) were less accurate. Method #6, based on the geometric means for monthly data seriously underestimates the annual phosphorus load.

Method #1 (mean Q,C) ignores the effect of correlation between flow and phosphorus concentration. As previously discussed, at the Main WWTP on several occasions, peaks in effluent phosphorus concentration were associated with peaks in flow as high levels of effluent suspended solids were discharged from the final clarifiers. As a result, flow was positively correlated to effluent phosphorus concentration (Table 4.5) and Method #1 underestimated annual phosphorus loading by 3% of the true load, representing for the Main WWTP approximately 10 tonnes.

Table 6.2:- Errors in Annual Phosphorus Loads Assuming Complete Flow & Concentration Records.

Estimation Technique:	Main:	Humber:	Highland Creek:
Method #1: Mean annual Q,C	-3%	2%	0%
Method #2: Mean annual Q,Cf	0%	0%	0%
Method #3: Mean annual L	0%	0%	0%
Method #4: Mean monthly Q,C	-4%	0%	0%
Method #5: Mean monthly Q,Cf	0%	1%	0%
Method #6: Mean monthly Q,Cg	-16%	-14%	-5%

Table 6.3:- Mean Errors in Annual Phosphorus Loads for 1000 Simulations For Weekly Sampling for Effluent Phosphorus Concentrations.

Estimation Technique:	Main:	Humber:	Highland Creek:
Method #1: Mean annual Q,C	-4%	-0%	-2%
Method #2: Mean annual Q,Cf	0%	-0%	0%
Method #3: Mean annual L	-2%	-2%	-2%
Method #4: Mean monthly Q,C	-3%	-0%	2%
Method #5: Mean monthly Q,Cf	1%	-0%	2%
Method #6: Mean monthly Q,Cg	-13%	-12%	-2%

In contrast, for the Humber WWTP, because of a slight negative correlation between flow and phosphorus concentration (low effluent phosphorus concentrations associated with high flows), Method #1 overestimated annual phosphorus loading by 2%. At the Highland Creek WWTP, because flow and effluent phosphorus concentration were uncorrelated, Method #1 neither overestimated nor underestimated the true loading.

6.3) Comparison of Results: Incomplete Data Record

Most Ontario WWTPs do not collect effluent samples and analyze phosphorus concentrations on a daily basis. Therefore, simulations were performed to compute errors for the load estimation techniques when the annual database consisted of a complete daily flow record but an incomplete daily phosphorus record.

A computer program was written to simulate the effect of weekly sampling. Currently, the MOE is considering adopting weekly sampling as the minimum frequency for WWTPs larger than 4546 m^3/d. Therefore, from the complete data sets (with missing values replaced by estimated values on the basis of first-order linear interpolation) for the three Metro Toronto WWTPs, the program selected a subset of 52 paired flow and effluent phosphorus concentration values. The program then calculated load estimates for the subset according to the various load estimation techniques in Table 6.1. Where required, the mean daily flows (calculated on either an annual or monthly basis) were provided by the program from the complete record of daily flows.

Estimated loads were compared to the "true load", previously determined as the sum of the product of the daily flows and concentrations for the complete data set. Table 6.3, which summarizes the results of the simulations for 1000 subsets, shows that in general the accuracy of estimates deteriorated as the frequency of sampling decreased. Four techniques (Methods #2 to #5) produced more accurate estimates in comparison to current load estimation technique (Method #1). As was the case for the complete data set, the use of geometric means (Method #6) resulted in very poor estimates.

Taking into account the results in both Table 6.2 and 6.3, the use of Method #2 (mean annual Q,Cf) resulted in the best accuracy for both cases. Method #5 (mean monthly Q,Cf) based on flow-weighted concentrations calculated on a monthly basis resulted in the second best estimate. Flow-weighting takes into account the effect of correlation between flows and effluent phosphorus concentration when used to calculate loading estimates. Method #3 (mean annual L) did not perform as well as the methods based on flow-weighted concentrations, but was still superior overall to Method #1. Hence loadings based on flow-weighted concentrations are recommended for the best estimates of true loadings from WWTPs.

7.) Alternatives for Reporting and Assessing Monthly Compliance:

Until recently, at large Ontario WWTPs which are not subject to site specific requirements, total effluent phosphorus concentrations have been limited to 1.0 mg/L, assessed as an annual mean. If the mean phosphorus concentration was less than 1.05 mg/L, the WWTP has been considered in compliance (Monteith, 1988). Currently, the MOE is implementing recommendations contained in the 1983 supplement to the Great Lakes Water Quality Agreement which requires compliance to be assessed on a monthly basis. Changing compliance from an annual to a monthly basis reduces target loadings to the Great Lakes Basins (Canviro, 1988d). Although effluent phosphorus levels for each month will be reported as arithmetic means, other statistics could be used.

A preliminary overview of the main technical issues concerning the selection of a statistic for reporting and assessing monthly compliance is presented in this chapter. Options for summarizing monthly phosphorus levels are presented and their advantages and disadvantages discussed in the light of information previously obtained from the study. To examine the performance of alternative statistics for reporting and assessing compliance, the results from simulations are presented and discussed.

The analysis and comments in this chapter should be regarded as preliminary and are intended to serve as a focus for further discussion and research.

7.1) Description and Application of Monthly Statistics:

A number of candidate statistics, in addition to the arithmetic mean, can potentially be used to summarize monthly WWTP performance and to assess monthly compliance. The principal ones include the flow-weighted mean, the geometric mean, and the median. Equations for calculating these values are given in

Table 7.1. Two additional statistics, the trimmed mean and the bi-weight (described by Reckhow and Chapra, 1983) were not examined in detail because of the difficulty in applying them to data sets containing only a few values, the case when sampling is infrequent.

Desirable features of a monthly statistic include computational simplicity, ability to reflect the nature of the distribution of effluent phosphorus concentrations, sensitivity and accuracy in detecting violations, and ease of use and accuracy when used to calculate annual phosphorus loads. Two other desirable properties include resistance and robustness. A statistic is resistant if its value is not greatly influenced by the removal of outliers and robust if its value does not depend on the shape of the data distribution (Bodo, 1987). The advantages and disadvantages of each statistic are discussed in light of these features in the following sections.

7.1.1) Arithmetic Mean:

a.) Advantages: The arithmetic mean is simple to calculate. There is wide familiarity on the part of managers, WWTP operators and the public concerning the use and meaning of the statistic. As shown in Chapter 6, the mean can be used in load estimation calculations (Method #4, Table 6.1). As the current definition of compliance is based on the arithmetic mean, there is a clear understanding of the relationship between compliance levels and total annual loading (Canviro, 1988a & 1988d).

b.) Disadvantages: In strict terms, calculating and reporting an arithmetic mean implies that the underlying population is normally distributed. In fact, as shown in Chapter 5, effluent phosphorus concentrations are more nearly log-normally than normally distributed. In contrast to more robust statistics, the arithmetic mean is affected by extreme

Table 7.1 Equations for Calculating Monthly Summary Statistics.

1.) Arithmetic Mean ($\overline{C}$):

$$\overline{C} = [\sum_{i=1}^{n_p} C_i]/n_p \quad \ldots\ldots [7.1]$$

where: C_i = daily total effluent phosphorus concentrations,
n_p = number of days in a month with phosphorus concentration records.

2.) Flow-Weighted Mean ($\overline{C}_f$):

$$\overline{C}_f = [\sum_{i=1}^{q} Q_i * C_i]/[\sum_{i=1}^{q} Q_i] \quad \ldots\ldots [7.2]$$

where: q = number of days in a month with both flow and phosphorus concentration records,

Q_i = flow rate on day with both flow and phosphorus concentration record;

3.) Geometric Mean ($\overline{C}_g$):

$$\overline{C}_g = \text{antilog}\ ([\sum_{i=1}^{n_p} \log C_i]/n_p) \quad \ldots\ldots [7.3]$$

where: $\log C_i$ = the logarithms of the daily TP concentrations,

n_p = as previously defined.

4.) Median [C(50)]: The np daily phosphorus concentrations in each month are ranked from smallest to largest. C(i) refers to the phosphorus concentration corresponding to rank i. The median is:

$$C(50) = C((n_p+1)/2) \quad \text{for } n_p \text{ odd}, \ldots\ldots [7.4]$$

$$= [C(n_p/2) + C((n_p/2)+1)]/2 \quad \text{for } n_p \text{ even.}$$

The median separates the ranked concentrations into two groups, 50% of the concentrations are smaller than the median and 50% are larger.

values or outliers (Bodo, 1987). One extreme value will change the value of the arithmetic mean. This property is a disadvantage if the extreme value is spurious (not a true value) but an advantage if the extreme is real, reflecting a process upset. Load estimates based on monthly arithmetic means (Method #4, Table 6.1) are inaccurate when flows are correlated to effluent phosphorus concentrations.

7.1.2) Flow-Weighted Mean:

a.) Advantages: Flow-weighted mean concentrations have physical significance; they represent the concentration of phosphorus in a well mixed reservoir containing the entire monthly effluent flow from the WWTP (Bodo, 1987). Load estimation calculations using flow-weighted monthly means (Method #5, Table 6.1) result in more accurate estimates in comparison to the procedure currently used. Flow-weighting better accounts for the effect of correlated flows and effluent phosphorus concentrations.

b.) Disadvantages: The calculation of flow-weighted means is slightly more complex than the calculation of arithmetic averages. As a consequence, the possibility of computational errors is increased. In addition, unreliable or inconsistent flow measurement will decrease the reliability and increase the variability of flow-weighted mean concentrations. As discussed for the arithmetic mean, values of the flow-weighted mean will be affected by extreme values (outliers).

7.1.3) Geometric Mean:

a.) Advantages: Effluent phosphorus data for the Main, Humber and Highland Creek WWTPs were most often log-normally distributed (Chapter 5). Accordingly, the geometric mean provides the best measure of central tendency of the candidate statistics. In addition, the statistic is not as sensitive to extreme values (outliers).

b.) Disadvantages: The statistic is more complex to calculate than the arithmetic mean and increases the possibility of computational errors. Geometric means reported by the WWTPs on a monthly basis cannot be used directly for load estimation without causing serious errors. Values for geometric means can be converted to arithmetic means using a calculated or an assumed variance (Aitchison and Brown, 1963). Such conversions are complicated.

The relationship between different compliance levels based on geometric means and total annual basin loadings is not known. Because phosphorus concentration distributions are positively skewed, compliance defined as 1.0 mg/L as a monthly geometric mean will permit the discharge of larger phosphorus loads in comparison to compliance based on an arithmetic average. Although effluent data for most WWTPs appear to be log-normally distributed, the log-normal distribution cannot be assumed to apply in all cases. For example, as discussed in Section 5.2, the probability distributions for the 1985 effluent concentrations for the Main WWTP were a mixture of two log-normal distributions.

7.1.4) Median:

a.) Advantages: Use of the median does not require any assumption regarding the underlying distribution of the population. In this sense it is the only statistic of the four that is "distribution free". Values of the median are not affected by extreme values (outliers).

b.) Disadvantages: The median suffers from the same disadvantages as the geometric mean: calculations are more complex than the arithmetic mean, medians cannot be used directly in load estimation calculation, and a median compliance level of 1.0 mg/L would allow phosphorus loadings to increase.

7.2) Comparison of Performance on Effluent Data:

A computer program was written to simulate the performance of the arithmetic mean, the flow-weighted mean, the geometric mean and the median using the data set for the Humber WWTP. First-order linear interpolation was used to estimate missing values (Press et al., 1986). Values for the four statistics obtained from different sampling frequencies were compared to values for the complete monthly data set. Data for the Humber WWTP were used because, of the three Metro Toronto WWTPs, Humber had a mean annual effluent phosphorus concentrations which was the closest to the 1.0 mg/L compliance level. Simulations with this data therefore provided a more severe test of the sensitivity of the statistic in detecting departures from compliance.

For each run of the simulation, the program randomly selected a sub-set of 30 days of data (one calendar month) from the 1985 Humber data set. The true arithmetic mean, flow-weighted mean, geometric mean, and median were calculated for the month. Secondly, from the monthly data set, additional subsets were selected at various frequencies (once per month, twice per month, once per week, twice per week, and three times per week) and the arithmetic means, flow-weighted means, geometric means, and medians calculated. Sampling without replacement was employed to select the subsets. Performance was evaluated by computing errors or the differences between the values for each of the statistics at the various frequencies and the corresponding true value for the same statistics from the complete monthly data set. For 300 runs, both mean errors and mean errors as a percentage of the true value were computed.

In addition, during each run the compliance status of the month as given by the four statistics was compared to the status for the same statistic at the lower frequencies based on the following four possible outcomes:

Statistic for complete month: < 1.05 mg/L?	Statistic at lower-frequency: < 1.05 mg/L?	Agreement?:
Yes	Yes	Yes
No	No	Yes
Yes	No	No
No	Yes	No

Results were expressed as percent agreement, the proportion of the 300 runs for which the true value and the value at the low frequency were in agreement with respect to compliance.

For each statistic the correlation coefficient was calculated between the value of the statistic at the low frequency and the true value of the statistic. Selected scatter plots for the two values were plotted to ensure that low values of the correlation coefficient were not due to the presence of non-linear relationships. Fig. 7.1 is typical of the plots.

Finally, the root mean square error (RMSE) was calculated for each case according to:

$$RMSE = [B^2 + S^2]^{1/2} \quad \text{..............................} [7.5]$$

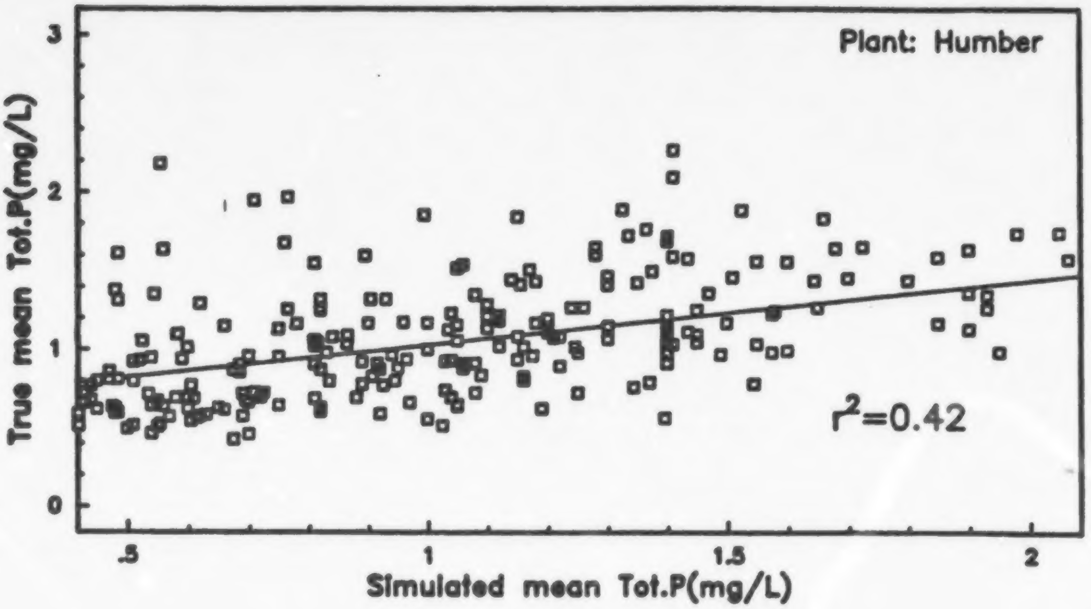
where: B = the bias (or error) of the method, and

S = the standard deviation of the method.

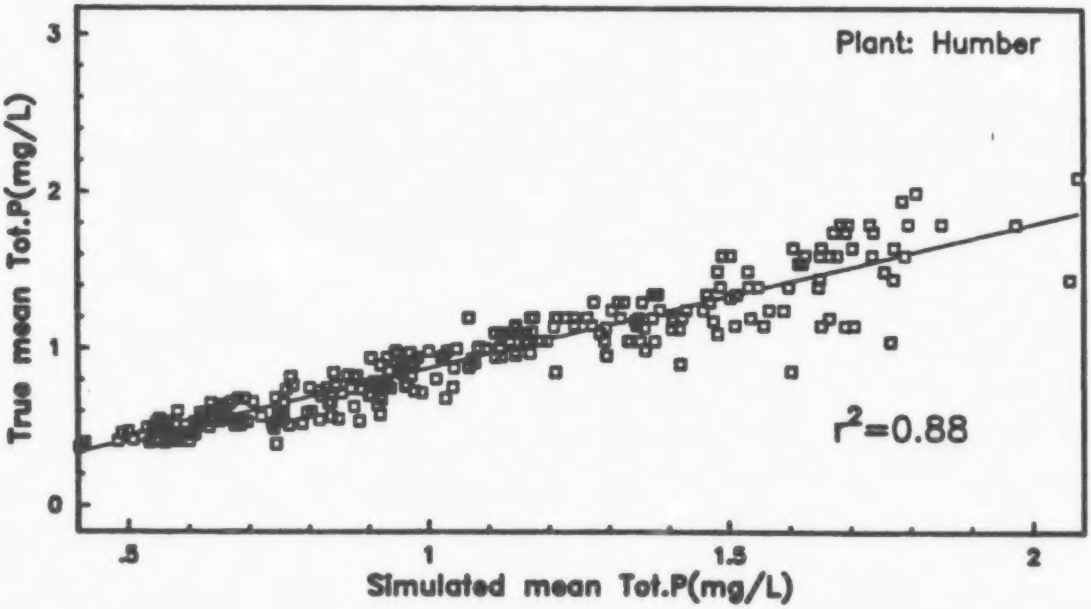
As discussed by Dolan et al. (1981), the RMSE allows the trade-off between precision and bias of estimates to be examined.

Figure 7.1:- Scatter Plots of 1985 Humber Data for Simulated and Observed Arithmetic Mean Effluent Phosphorus Concentrations

Arithmetic Mean: Simulation at "twice monthly" sampling



Arithmetic Mean: Simulation at "three times per week" sampling



As seen from the simulation results, Table 7.2, arithmetic and flow weighted mean concentrations are nearly identical at each frequency. Similarly there is little difference between the geometric mean and the median concentrations. The latter two are lower than the former two due to the skewed nature of the effluent phosphorus distribution. The geometric mean and the median tended to overestimate monthly levels at low sampling frequencies (1/month and 2/month).

Mean biases for the geometric mean and the median were larger than for the arithmetic and flow-weighted means at low sampling frequencies. For sampling frequencies greater than once per week, the geometric mean had the lowest RMSE values. However, in general none of the four statistics demonstrated greatly superior performance in comparison to the others. Therefore, a decision to change the arithmetic mean as the reporting statistic should be based on primarily on ease of computation, resulting accuracy when used in load estimate calculations, and ability to manage total annual phosphorus loads, factors previously discussed.

The results in Table 7.2 indicate that a sampling frequency of twice per week provides a slightly better estimate of the arithmetic and flow-weighted mean in comparison to a frequency of once per week. However, such results are only valid provided that the sampling days in a given week are selected randomly. The presence of weekly variations in effluent quality combined with a strategy which requires sampling on the same days of the week can potentially bias estimates. Additional factors which influence the selection of a frequency of sampling include ease of administration of the sampling program, the size of the phosphorus load discharged, the sensitivity of the receiving water and requirements for process control.

Table 7.2:- Effect of Sampling Frequency on Estimates of Monthly Statistics of Effluent Phosphorous Concentrations (300 Simulations).

Sampling Frequency	Parameter:	Arithmetic Mean	Flow-Weight Mean	Geometric Mean	Median
1/month	Mean Concentration	1.08	1.08	1.08	1.08
	Mean Bias	1%	1%	18%	17%
	Compliance Agreement	70%	70%	69%	71%
	Correlation Coefficient	49%	49%	50%	50%
	RMSE	0.72	0.72	0.75	0.75
2/month	Mean Concentration	1.05	1.05	0.96	1.05
	Mean Bias	2%	2%	5%	13%
	Compliance Agreement	77%	76%	79%	76%
	Correlation Coefficient	65%	65%	64%	64%
	RMSE	0.60	0.61	0.56	0.62
1/week	Mean Concentration	1.05	1.05	0.93	0.97
	Mean Bias	2%	2%	1%	5%
	Compliance Agreement	81%	81%	81%	74%
	Correlation Coefficient	75%	75%	74%	68%
	RMSE	0.46	0.47	0.41	0.46
2/week	Mean Concentration	1.07	1.07	0.93	0.95
	Mean Bias	0%	0%	1%	2%
	Compliance Agreement	86%	87%	83%	77%
	Correlation Coefficient	89%	89%	88%	85%
	RMSE	0.41	0.42	0.36	0.41
3/week	Mean Concentration	1.07	1.08	0.93	0.94
	Mean Bias	0%	0%	1%	2%
	Compliance Agreement	92%	92%	92%	85%
	Correlation Coefficient	93%	93%	93%	91%
	RMSE	0.39	0.40	0.34	0.39
daily	Mean Concentration	1.07	1.07	0.92	0.93
	Mean Bias	0%	0%	0%	0%
	Compliance Agreement	100%	100%	100%	100%
	Correlation Coefficient	100%	100%	100%	100%
	RMSE	0.36	0.37	0.31	0.34

8. Precision of Mean Effluent Phosphorus Concentrations & Load Estimates:

8.1) Precision for Metro Toronto WWTPs:

Using the definition of precision as given in equation 2.4 and the previous summary statistics (Table 5.3 and Appendix A.4), precision estimates were calculated for the Main, Humber, and Highland Creek WWTPs. Table 8.1 summarizes the results for annual and monthly mean phosphorus concentrations. Annual values varied from approximately 4% to 10% for the three WWTPs. Because monthly variability tended to be higher and fewer samples were collected, monthly means were less precise, ranging from 8% to 42%.

Table 8.2 provides a summary of the precisions for the mean annual and monthly phosphorus loads for the three WWTPs. Appendix A.6 also lists monthly phosphorus loading precisions for the three WWTPs for each month in 1985. The values are similar to and slightly higher than those for the mean phosphorus concentrations. Precisions for the annual load estimates ranged from 4% to 12% while the monthly estimates ranged from 8% to 65%.

As noted in Section 6.5, short-term autocorrelation was observed in the daily phosphorus concentrations and loads. Serial correlation invalidates the assumption of random sampling upon which the definition of precision (equation 2.4) was based. Because the net effect of serial correlation is to widen the confidence limits on the mean, equation 2.4 underestimates the uncertainty associated with autocorrelated data (Sanders et al., 1987). Accordingly, the precision estimates for the three WWTPs were recalculated, correcting for serial correlation using:

$$d'\% = d\%*C.F. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [8.1]$$

where: $d'\%$ = precision estimate corrected for serial correlation,

Table 8.1:- Precison Estimates for Means of Annual & Monthly Phosphorus Concentrations for Three Metro Toronto WWTPs.

Plant:	Annual Mean (mg/L)	Precision (%)	Precision (Monthly Mean)		
			Min. Value (%)	Max. Value (%)	Mean (%)
Main	1.122	10%	8%	42%	21%
Humber	1.074	7%	14%	30%	21%
Highland Creek	0.766	4%	8%	20%	12%

Table 8.2:- Precison Estimates for Means of Annual & Monthly Phosphorus Loads for Three Metro Toronto WWTPs.

Plant:	Annual Mean (kg/d)	Precision (%)	Precision (Monthly Mean)		
			Min. Value (%)	Max. Value (%)	Mean (%)
Main	983.4	12%	8%	65%	26%
Humber	393.8	7%	17%	31%	22%
Highland Creek	124.6	4%	9%	19%	12%

Table 8.3:- Precison Estimates (Accounting for Serial Correlation) for Means of Annual & Monthly Phosphorus Concentrations and Loads for three Metro Toronto WWTPs.

Plant:	Phosphorus Concentration		Phosphorus Load	
	Annual Mean (mg/L)	Precision* (%)	Annual Mean (kg/d)	Precision* (%)
Main	1.122	15%	983.4	17%
Humber	1.074	12%	393.8	13%
Highland Creek	0.766	6%	124.6	6%

Precision = t*c.v.*C.F./sqrt(N)

d% = precision estimate calculated from equation 2.4,

C.F. = correction factor to account for effect of serial correlation.

The correction factor, C.F., was determined using the values for the lag 1 autocorrelation coefficients [r(1)] from Table 5.6 and assuming first-order autoregressive time dependence. From Sanders et al. (1987) and Gilbert (1987) the appropriate relationship is given as follows:

$$C.F. = (1 + (2/n)[\sum_{k=1}^{n} (n-k)r_k])^{1/2} \text{ ....} [8.2]$$

where: n = the number of samples collected per year, Table 5.3,

r_k = the sample autocorrelation coefficients at lag k.

Values for r_k were included in equation 8.2, above, only if they were significant. Significance was established as follows (Chatfield, 1984):

$$r_k \geq 2/n^{1/2} \text{ ....} [8.3]$$

where: r_k,n = as previously defined.

Table 8.3 lists the values for precision accounting for serial correlation. For annual phosphorus concentrations, they range from 6% to 15% and, for annual loads, from 6% to 17%. For Humber, accounting for the effects of serial correlation resulted in roughly a two-fold increase in the uncertainty of the annual phosphorus concentration and load estimates. It is quite clear, therefore, that confidence limits for annual and monthly mean concentrations from WWTPs are too narrow if the WWTP practices daily sampling (as was the case for the three selected WWTPs) and the effects of serial correlation are ignored.

8.2) Precisions for Basin Wide Estimates:

8.2.1) Overview of Approach:-

A major objective of the study was to estimate the uncertainty associated with the total phosphorus load and aggregate average phosphorus concentration for each of the Great Lakes Basins. To do this, knowledge about the performance of the three Metro Toronto WWTPs was applied to other WWTPs in the basins, in effect reasoning from the specific to the general. Appendix A.7 provides a detailed description of the procedure.

To calculate basin precisions, two major sets of assumptions were adopted. One set of assumptions was used to estimate the unknown effluent phosphorus variabilities (uncorrected for serial correlation). In the first method, the standard deviation of the effluent phosphorus concentration at a WWTP was determined from the product of the annual mean phosphorus concentration (from Canviro, 1988a) and the average annual coefficient of variation for effluent phosphorus for the three Metro WWTPs. An alternative procedure involved the regression of monthly effluent phosphorus standard deviations on the corresponding monthly means for the Metro Toronto WWTPs. The estimated annual effluent phosphorus standard deviation was then determined as a regression prediction, knowing the mean annual effluent phosphorus concentration.

A second set of assumptions was used to correct the variability estimates for the effects of serial correlation. Adopting the approach used in the preceding section, the time-dependence structure of the effluent phosphorus concentrations was assumed to follow a simple Markov (or first-order autoregressive) model. Lag 1 autocorrelation coefficients [r(1)'s] of 0.4, 0.5 and 0.6 were selected, a range which covered the r(1) values calculated for the three Metro WWTPs (see Table 5.6). Following application of equation 8.3, significant values of the autocorrelation coefficients [r_k] were included in equation 8.2 to calculate a correction term. Correction factor (C.F.) values were then related to the number of samples collected per year at a WWTP. As indicated in Appendix A.7, on the basis of these assumptions, variabilities were corrected for serial correlation if the frequency of phosphorus sampling exceeded once every second day (182 samples per year). Estimates were not corrected if the sampling frequency was below 182 samples per year.

With the two sets of assumptions, the variabilities of mean phosphorus concentration and load were calculated for each WWTP in a basin knowing the mean phosphorus concentration and the total number of phosphorus concentrations collected during the year. Using relationships provided by Sachs (1984), a combined variability for all the WWTPs in a basin was computed from the individual variabilities at each of the WWTPs. Precision was then calculated as per equation 2.4.

8.2.2) Rationale for Approach:-

The procedure to obtain precisions extrapolates results from the three Metro Toronto WWTPs to other WWTPs in the basin. A key question is, therefore, how representative are the three Metro WWTPs of the other municipal WWTPs in the three Great Lakes Basins? A discussion is provided as follows:

a.) WWTP Type:-

The three Metro WWTPs are all conventional activated sludge WWTPs which practice chemical addition for phosphorus removal. The majority of the phosphorus load to the Lake Ontario and Lake Erie Basins comes from WWTPs of this type. However, as shown in Section 3.2, about half of the total phosphorus load to the Upper Great Lakes Basin comes from WWTPs which do not practice chemical addition for phosphorus removal. The three Metro WWTPs are therefore clearly not representative of those in the Upper Great Lakes Basin and no precisions were calculated for this basin.

Assuming that variability increases with the mean effluent phosphorus concentration, as was observed for the three Metro WWTPs, conventional activated sludge processes should have higher variabilities than WWTPs with effluent polishing and lower variabilities than those not adding chemicals (see Table 3.1). Therefore, for Lake Erie the resulting precisions would tend to be overestimates, whereas for Lake Ontario the procedure would tend to result in underestimates (see Fig. 3.1).

b.) Performance:-

The annual effluent phosphorus concentrations were 1.12 mg/L for Main, 1.07 for Humber and 0.77 for Highland Creek. This range covers the performance of most of the major WWTPs in the Lake Erie and Lake Ontario Basins. One notable exception is Hamilton's Woodward Ave. WWTP which averaged an effluent phosphorus concentration of 1.23 mg/L in 1984 and 1.30 in 1985.

c.) WWTP Size:-

The three Metro Toronto treatment WWTPs are among the largest in the province. In this respect, they are not representative of the majority of the WWTPs in the Lake Ontario and Lake Erie Basins. However, in a published study analyzing the 43 activated sludge WWTPs, Niku et al. (1981) were unable to establish any relationship between WWTP size and effluent variability.

d.) Chemical Type:-

The Main, Humber and Highland Creek WWTPs use ferrous chloride for phosphorus removal. The majority of WWTPs in the Lake Erie and Lake Ontario Basins also use iron salts for phosphorus removal. However, the adequacy of dosage control and the dosage rate itself have more to do with the variability of the effluent phosphorus concentration from a WWTP than the type of chemical used (Canviro, 1988d).

8.2.3) Results:-

As previously outlined, calculation of precisions for basin-wide estimates depended on the extrapolation of results from the Metro Toronto WWTPs to the other WWTPs in the basin. To test the sensitivity of the results to the nature of the extrapolations, precisions were estimated for a number of differing assumptions. Two different methods for calculating WWTP variabilities and three levels of serial correlation were examined. The results are summarized in Table 8.4.

Not surprisingly, Table 8.4 shows that values for precision varied according to the assumptions adopted. In particular, as for the Metro Toronto WWTPs, precisions for the basin were affected by accounting for the effects of serial correlation. Uncorrected for serial correlation, precisions for both total basin loads and aggregate average phosphorus concentrations were estimated to be in the 2-3% range for Lake Erie and 3-4% for Lake Ontario. Correcting for serial correlation, precisions ranged from roughly 2-4% for Lake Erie and 5-6% for Lake Ontario.

These results indicate that uncertainties are larger for the Lake Ontario estimates than those for the Lake Erie Basin. The uncertainties are different because the overall performance of the WWTPs in the Lake Erie Basin is better than those in the Lake Ontario Basin. In 1985, aggregate annual phosphorus concentrations were 0.80 and 0.93 for the Lake Erie and Lake Ontario Basins. The procedure for calculating the estimates assumes that variability (hence uncertainty) is higher at higher phosphorus levels.

Table 8.4:- Precisions for Basin Phosphorus Loadings and Aggregate Average Phosphorus Concentrations.

				Precison (%):	
Basin & Year:	Method:	No Corr.:	r(1)=0.40	r(1)=0.50	r(1)=0.60
Lake Ontario					
1984	#1:	3.5%	5.3%	5.4%	5.4%
	#2:	3.3%	5.1%	5.1%	5.1%
1985	#1:	4.1%	6.1%	6.2%	6.3%
	#2:	3.9%	6.0%	6.0%	6.0%
Lake Erie					
1984	#1:	2.9%	3.3%	3.7%	3.9%
	#2:	1.8%	2.1%	2.2%	2.4%
1985	#1:	2.7%	3.2%	3.5%	3.7%
	#2:	1.8%	2.0%	2.2%	2.3%

Further analyses were conducted to determine how the precisions would be affected should all WWTPs in the Lake Ontario Basin be brought into compliance. Under these conditions, some of the major WWTPs would produce a less variable effluent. Precision estimates were therefore recalculated assuming that WWTPs which reported a mean annual total phosphorus effluent concentrations of more than 1.0 mg/L achieved an effluent concentration of 1.0 mg/L on an annual basis. WWTPs affected in this way in the 1984 data base included Metro Toronto Humber, Halton Hills (Georgetown), Hamilton (Woodward Ave), Iroquois, Napanee, Newscastle (Port Darlington), Oshawa (Harmony Creek No. 2), Port Colborne (Seaway), and Whitby (Pringle Creek No. 2). All other WWTPs were assumed to have total phosphorus effluent concentrations as reported in the 1984 database. Examination of the results indicated that the precision estimates (expressed as a percentage) were not particularly sensitive to the performance of WWTPs out of compliance in 1984. The precision estimates listed in Table 8.4, therefore, should provide managers with a rough guideline in selecting phosphorus load reductions not contained in the 95% confidence interval of the total basin loading estimate.

Additional implications of the precision estimates are presented in the following section.

9.) Implications and Recommendations for Phosphorus Management:

9.1) Distribution of Loads and Status of Removal Practices:

Although there are approximately 400 municipal WWTPs in Ontario, most of the phosphorus loading from municipal sources originates from a few large WWTPs. This is particularly true of the Lake Ontario and Upper Great Lakes Basins where the three largest WWTPs in each basin account for the majority of phosphorus loading. Because loading in these two basins is dominated by a few key WWTPs, basin-wide management strategies for the Lake Ontario and Upper Great Lakes Basins should focus on improving performance at these WWTPs.

To complete the implementation of conventional phosphorus removal technology in the Lake Ontario Basin, chemical addition should be permanently instituted at the Hamilton (Woodward Ave) WWTP. In addition, consideration should be given to increasing the frequency of effluent sampling at the Burlington, Kingston, and Peterborough WWTPs. The three largest WWTPs in the Lake Ontario Basin--Main, Hamilton, and Humber--have been routinely out of compliance. Accordingly, daily effluent flows, total effluent phosphorus and total suspended solids concentrations from the three WWTPs should be examined by the MOE on an annual basis using probability and time-series plots to identify trends in performance and operational problems.

Municipal WWTPs in the Upper Great Lakes Basin lag behind in the implementation of conventional phosphorus removal technology. At the time this report was prepared, almost half of the phosphorus from municipal sources in the Upper Great Lakes Basin originated from WWTPs which did not practice chemical addition. Implementation of conventional phosphorus removal technology at the Sudbury and Sault Ste. Marie WWTPs will improve conditions in the Upper Great Lakes Basin. Consideration should be given to increasing the frequency of sampling for effluent phosphorus at the Sault Ste. Marie and Sudbury WWTPs to better assess WWTP performance and to optimize chemical addition.

The status of implementation of conventional phosphorus removal in the Lake Erie Basin stands in contrast to the other two basins. There is a more uniform distribution of the total basin load among the WWTPs in the basin in comparison to the other two. All WWTPs in the basin practice chemical addition for phosphorus removal. In addition, there are more WWTPs in the Lake Erie Basin with effluent polishing. Therefore, in contrast to the other two basins, improved phosphorus removal cannot be achieved by implementing improved operation at a few large WWTPs currently out of compliance. Further reductions in phosphorus loading from municipal treatment WWTPs will require that WWTPs consistently operate below the 1.0 mg/L compliance limit or that tertiary treatment be added at more WWTPs. Either way, substantial reductions in phosphorus loading from municipal WWTPs in the Lake Erie Basin will be increasingly difficult and expensive to achieve. The Ministry of Environment should examine the feasibility of reducing phosphorus loads to Lake Erie from other sectors (ie. non-point sources).

9.2) WWTP Phosphorus Concentrations and Load Estimates:

For the Welland and Waterloo WWTPs, an eight-day intensive sampling program indicated that diurnal fluctuations in influent phosphorus concentrations were damped in the effluent by chemical addition. As a result, there was little difference (2% or less) between values obtained from any of the sampling methods investigated (8-h equal volume composites, 24-h equal volume composites, 8-h flow-weighted composites and 24-h flow-weighted composites). However, for the Galt WWTP, diurnal fluctuations were evident in effluent total phosphorus concentrations as high levels of particulate phosphorus were discharged during the intensive sampling period. Eight-hour composites (either flow-weighted or equal volume) resulted in mean daily effluent concentrations which were 15-20% lower than 24-h flow-weighted composites for the same day. There was little difference (2% or less) between 24-hour equal volume and flow-weighted composites at Galt. These results suggest that, for most WWTPs, mean daily concentrations are not sensitive to the compositing procedure. However, for WWTPs which experience problems with phosphorus removal, 8-h composites will lead operators to underestimate mean concentrations. For this reason, the MOE should encourage WWTPs to collect 24-h composites and discourage the use of grab and 8-h composites.

Daily effluent phosphorus concentrations and loads for the three Metro Toronto treatment WWTPs were serially correlated. The presence of serial correlation violates the assumption of independence upon which most classical statistical analyses are based. In particular, confidence limits for annual or monthly mean concentrations calculated without taking autocorrelation into account will be underestimated, indicating a greater degree of precision than is in fact justified. Assuming that the results from the three Metro Toronto WWTPs are typical, serial correlation should be taken into account for confidence limit calculations when the sampling frequency is greater than once every other day (182 samples per year).

Currently, the MOE is proposing to define compliance as 1.0 mg/L based on a monthly mean instead, as is presently the case, on an annual mean. Defining compliance in these terms will increase uncertainty in establishing a statistically significant difference between the observed mean and the compliance level. As shown by the analysis of the data from the three Metro Toronto WWTPs, the uncertainty increased when phosphorus means were calculated on a monthly instead of an annual basis. Not accounting for the effects of serial correlation, precisions ranged from 4-10% for annual total phosphorus concentrations for the Main, Humber, and Highland Creek WWTPs. On a monthly basis, mean precisions ranged from 12-21% (Table 8.1). Uncertainty increased with monthly means because fewer samples were used to calculate the statistic and because process variability was generally higher on a monthly basis compared to an annual basis.

The principal advantage in retaining the arithmetic mean as a basis for assessing monthly compliance is that the link between different compliance limits and the total basin loadings has been established (Canviro, 1988a, 1988d). Although other statistics can be used as alternatives for reporting and assessing monthly compliance, the relationship between different monthly levels based on these statistics and total annual basin loadings is not known. Secondly, simulations comparing the arithmetic mean, flow-weighted mean, geometric mean, and the median did not reveal major differences in performance when compared at the same sampling frequency. Additional work is therefore required prior to changing in compliance assessment. Any statistic or scheme for reporting and assessing monthly compliance should be judged based on its ability to reflect the nature of the distribution of effluent phosphorus concentration, its sensitivity and accuracy in detecting violations, and its suitability in annual phosphorus load calculations. No matter what method is used a certain amount of discretion in enforcing compliance is inevitable. The ultimate success of a compliance policy must be judged in terms of annual total basin phosphorus loads.

9.3) Basin Phosphorus Concentrations and Load Estimates:

The current load estimation technique underestimated the 1985 annual phosphorus loading from the Main WWTP by 10 tonnes. Although the difference between the estimated load for current procedure and the true load is only 3% of the total phosphorus load for the Main WWTP, the difference is important when the stated management objective is to control (and, hence, to estimate) total basin phosphorus loading from all municipal sources to the Lake Ontario Basin to within 50 tonnes per year.

The current technique underestimated the 1985 Main phosphorus load because it failed to account for the effect of correlation between flow and effluent phosphorus concentration. Because the degree of underestimation varies with the flow and operating conditions at the WWTP, it will be random from year to year. For years during which flows are high, there will be a high carry over of total suspended solids in the effluent from the Main WWTP resulting in a comparatively higher correlation between flow and effluent phosphorus concentration. Consequently, for these years, the annual phosphorus loading from the Main WWTP will be seriously underestimated using current practices in comparison to dry years. Similarly, phosphorus loadings from other hydraulically overloaded WWTPs would probably be underestimated by the current estimation procedures. Variation in the degree of underestimation introduces uncertainty into the basin estimates.

Results from a computer program used to simulate the effect of weekly sampling showed that the accuracy of estimates generally deteriorated as the frequency of sampling decreased. Assuming once per week sampling, the current load estimation technique underestimated the 1985 Main load by 4% or 16 tonnes, on average.

A number of load estimation techniques are superior to the one currently used. Taking into account the results for daily sampling and simulated once per week sampling, Method #2 (Table 6.1), based on the mean annual flow rates and flow-weighted phosphorus concentrations, resulted in the best accuracy of all the methods tested. Method #5 (Table 6.1) based on mean flows and flow-weighted concentrations calculated on a monthly basis resulted in the second best estimates. Flow-weighting takes into account the effect of correlation between flows and effluent phosphorus concentration.

Total phosphorus loads and aggregate average phosphorus concentrations for the three basins are estimates. For each estimate, there is a corresponding level of uncertainty or imprecision which must be taken into account when using the estimates to manage water quality. Based on the level of performance and sampling frequencies in 1985, precisions for total basin load and aggregate average phosphorus concentration were estimated to be in the range of 2-4% for Lake Erie and 5-6% for Lake Ontario. In terms of total phosphorus load this corresponds to 5-10 tonnes for Lake Erie and 50-60 tonnes for Lake Ontario. The uncertainty of the basin-wide estimates will decrease as the overall efficiency of phosphorus removal of WWTPs in the basin improves.

Precision estimates establish the minimum load reduction for each basin which can be detected from the year-to-year changes in overall basin loading occurring by chance. With respect to the current MOE proposal to reduce the total load to Lake Ontario by 50 tonnes per year (5%) and to Lake Erie by 30 tonnes per year (12%), it is the authors' judgment that, for Lake Ontario, the stated objective is achievable but not detectable. In contrast, for Lake Erie, the reverse case is true; a reduction of 30 tonnes per year is detectable but not achievable through the implementation of conventional phosphorus removal technology or improved operation.

9.4) Sources of Bias in Load and Concentration Estimates:

In addition to load estimation techniques, there are a number of other potential sources of bias in both the phosphorus load and concentration estimates. These are identified and discussed as follows:

a.) Flow Measurement:- Inaccurate flow measurement is potentially one of the greatest sources of inaccuracy in load estimation. In particular, because the total phosphorus load from the Lake Ontario and Upper Great Lakes Basins are dominated by a few large WWTPs, inaccurate flow measurements at these WWTPs can seriously impact the phosphorus load estimates for the entire basin.

b.) Data Round-Off:- The supplemental information provided by Canviro Consultants contained tabulated monthly averages for flow and phosphorus concentrations for each of the WWTPs. Inspection of these tables indicated that current practices are inconsistent with respect to round-off of summary statistics. For some WWTPs, the database contains monthly mean phosphorus concentrations expressed to one decimal place and a trailing zero (X.X0), while for other WWTPs the mean is expressed to two decimal places (X.XX). The difference between rounding-off phosphorus means to one or two decimal places resulted in a difference of 7 tonnes for the 1985 phosphorus load estimated for the Main WWTP. Sachs (1984) recommends that values for mean and standard deviation be reported with one or at most two decimal places more precise than the original data. Reporting values to two decimal places is appropriate when the sample size is large.

c.) WWTP Bypass:- During high flow periods, many municipal WWTPs practice WWTP bypass to prevent the washout of solids. The questionnaire completed by Canviro (1988a) indicated that six WWTPs [Georgetown (Halton Hills), Oakville South East, Oakville South West, Halton Hills (Acton), Welland and Milton] bypass flows sometime during the year. For some of these WWTPs, the bypass was included in the effluent sample analyzed for phosphorus while for others it was not.

Ideally, bypass should be excluded from effluent samples so that the effluent concentrations only reflect the performance of the treatment WWTPs. Bypass flows should then be sampled separately to estimate phosphorus loading from this source. A consistent approach regarding effluent sampling is essential for all WWTPs.

10.) Key Findings:

In support of current efforts by the Ontario Ministry of the Environment to develop basin-wide management strategies to reduce phosphorus loading to the Great Lakes from municipal treatment WWTPs, an evaluation was conducted to estimate the precision of basin loadings and examine techniques for sample collection and data analysis. The main conclusions are as follows:

* Table 10.1 contains a number of key results from the study. These findings indicate that further reductions in phosphorus loading from municipal WWTPs in the Lake Erie Basin will be difficult to obtain through upgrading the operation of existing WWTPs. In the Lake Ontario Basin, significant reductions in phosphorus loading can be achieved by upgrading the performance of large WWTPs in the basin. In the Upper Great Lakes Basin, a number of WWTPs require upgrading to conventional phosphorus removal.

* A reduction in phosphorus load of 50 tonnes per year (5% of the total annual load) for the Lake Ontario Basin, as proposed by the MOE, is achievable but probably cannot be detected from the naturally occurring year-to-year variation in the total load estimate. In contrast, the proposed reduction for the Lake Erie Basin of 30 tonnes per year (12% of the total annual load), although larger than the uncertainty associated with the load estimate, will be difficult and possibly expensive to achieve.

* At the Welland, Waterloo, and Galt WWTPs, strong diurnal fluctuations in influent total and soluble phosphorus concentrations were detected during an intensive eight-day sampling program. Eight-hour equal volume or flow-weighted composites underestimated mean daily influent phosphorus concentrations in comparison to 24-h flow-weighted composites. Differences were negligible between 24-h equal volume and flow-weighted composites.

Table 10.1:- Summary of Results from Study.

Parameter:	Lake Erie:	Lake Ontario	Upper Great Lakes
1985 TP Load (tonnes)	250	950	320
1985 Aggregate Aver. TP Conc. (mg/L)	0.80	0.93	1.50
TP Conc. & Load Precision	2-4%	3-6%	--
% Total Basin TP Loads:			
Plants Not Adding Coagulant	0%	16%	43%
Primary Plants	23%	8%	59%
From 3 Largest Contributors	39%	56%	70%
Three Largest TP Contributors & 1985 TP Conc. (mg/L)	1. Greenway (London) 0.77 2. Westerly (Windsor) 0.86 3. Guelph 0.83	1. Toronto (Main) 1.09 2. Hamilton (Woodward) 1.31 3. Toronto (Humber) 1.08	1. Thunder Bay 1.01 2. Sudbury 2.10 3. Sault Ste Marie(old) 1.56

* For the Welland and Waterloo WWTPs, diurnal fluctuations in influent total phosphorus concentrations were damped out by the time they reached the effluent. Differences were negligible between daily mean concentrations for the various sampling methods (24-h flow-weighted composites, 8-h flow-weighted composite, 24-h equal volume composites, and 8-h equal volume composites). However, for the Galt WWTP which discharged high levels of particulate phosphorus during the intensive sampling period, 8-h equal volume or flow-weighted concentrations underestimated mean daily influent phosphorus concentrations by 15-20%. For this WWTP, the mean daily values from 24-h equal volume composites were within 5% of those from 24-h flow-weighted composites.

* An examination of effluent data from the Main, Humber, and Highland Creek WWTPs indicated that, in general, flows, effluent phosphorus concentrations, and daily phosphorus loadings were log-normally distributed. However,in some cases, the data distributions had longer tails than the log-normal distribution and appeared to be a mixture of two distributions--one distribution representing process conditions under normal operation and a second representing upset conditions.

* For all three Metro Toronto WWTPs, phosphorus loading was highly correlated to phosphorus concentration but poorly correlated to flow.

* The coefficients of variability--the ratio of the standard deviation to the mean--were 0.91, 0.67, and 0.38 for annual effluent total phosphorus concentrations from the Main, Humber, and Highland Creek WWTPs respectively.

* Daily effluent phosphorus concentrations and loads for the Main, Humber, and Highland Creek WWTPs were serially correlated. Accordingly, confidence limits for means calculated without correcting for serial correlations underestimated the uncertainty associated with the mean. Serial correlation influences results for WWTPs sampling for effluent phosphorus more than once every

other day (182 samples per week).

* Defining compliance on a monthly rather than an annual basis will increase the uncertainty associated in establishing, in statistical terms, when a WWTP is out of compliance.

* Simulations comparing the arithmetic mean, flow-weighted mean, geometric mean, and the median did not reveal major differences in performance.

* Annual phosphorus loads from a treatment WWTP are currently estimated based on the arithmetic means for flow and effluent phosphorus concentration from the annual data. This technique underestimated the 1985 annual phosphorus from the Main WWTP by approximately 10 tonnes per year. Assuming once per week sampling, the 1985 Main load was underestimated by 4% or 16 tonnes, on average. The procedure failed to account for the effect of correlation of flow with effluent phosphorus. Because the degree of correlation is likely variable from year to year, the degree of underestimation is also likely variable from one year to another.

* The use of load estimation Method #2 (Table 6.1) resulted in no errors in the annual loads for the Main, Humber, and Highland Creek WWTPs both for complete and incomplete annual data records. Method #5 (Table 6.1) resulted in the second best estimates. Both procedures are based on flow-weighting the mean phosphorus concentrations. Flow-weighting accounted for the effect of correlation between flows and effluent phosphorus concentration in load estimates.

11.) Key Recommendations:

The main recommendations arising from the study are as follows:

* In developing basin wide management strategies, the Ministry of the Environment should not propose load reductions smaller than 2-4% of the total basin load for Lake Erie or 3-6% for Lake Ontario. Load reductions smaller than these cannot be distinguished from the natural year-to-year variations in estimated basin-wide loadings.

* The feasibility of implementing further reductions in phosphorus loading to Lake Erie from sources other than municipal WWTPs should be investigated.

* Resources and efforts to reduce phosphorus loading in the Lake Ontario and Upper Great Lakes Basins should be focused on WWTPs contributing the largest loads in each basin (Table 10.1). In particular, chemical addition for phosphorus removal should be permanently instituted at the Hamilton (Woodward Ave.) WWTP.

* Estimates of mean daily effluent phosphorus concentration should be based on 24-hour equal volume or flow-weighted composites. Eight-hour equal volume or flow-weighted composites should be avoided because of the potential for underestimating mean daily total phosphorus concentrations at WWTPs experiencing problems with phosphorus removal.

* Daily data from the Toronto (Main), Hamilton (Woodward Ave) and Toronto (Humber) WWTPs should be analyzed graphically and statistically on an annual basis to assess WWTP performance.

* Substitution of another statistic for the arithmetic mean for reporting monthly compliance should not be made without further study of the implications of such changes on the management of annual phosphorus discharges.

* Load estimates should be calculated using annual mean flows and either annual mean flow-weighted concentrations (Method #2, Table 6.1) or monthly mean flow-weighted concentrations

(Method #5, Table 6.1).

* The Ministry of the Environment should inspect a few of the largest WWTPs in each basin on an annual basis to confirm flow rate measurements.

* Mean monthly effluent phosphorus concentrations should be reported and stored to two significant figures (ie. as X.XX mg/L) for all WWTPs, provided two or more samples per month are collected.

* Bypass flow should be excluded from effluent samples so that effluent concentrations only reflect the removal efficiencies of the WWTP.

* A study should be conducted to estimate the annual phosphorus load resulting from WWTP bypass. This estimate should be reported along with yearly estimates of total basin loading. As for other management strategies, the efforts should start at WWTPs which contribute the largest phosphorus load contribution to each basin.

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Appendix 1

A.1 Specifications & Performance of Ontario Municipal Treatment WWTPs

Table A.1.1:- Specifications & Performance of Ontario Municipal WWTPs in the Lake Ontario/St. Lawrence River Basin.

LAKE ONTARIO/ST. LAWRENCE BASIN:

PLANT	PLANT TYPE	CHEMICAL	FROM MOE DATA 1981-85 DAILY FLOW m^3/day*1000	TOTAL P CONC. mg/L	NUMBER OF SAMPLES PER MONTH 1984-85 average	APPR. ANNUAL P LOAD tonnes/year	PERCENT TOTAL LOAD %
Belleville WPCP	C.A.S	Fc./Fe.C.	34.30	1.09	16.3	13.7	1.4%
Brockville WPCP	P.	Fc.C.	15.79	1.30	5.7	7.5	0.7%
Burlington WPCP	C.A.S	Fc.C.	78.07	0.79	3.8	22.5	2.2%
Caledon WPCP	C.A.S.	no	3.57	0.38	3.1	0.5	0.0%
Campbellford WPCP	C.A.S	no	6.98	0.73	0.9	1.9	0.2%
Cobourg WPCP No. 1	C.A.S.	no	12.95	0.98	1.5	4.6	0.5%
Cornwall WPCP	P.	A./P.	48.32	1.26	14.6	21.9	2.2%
Dundas WPCP	C.A.S./E.P.	A.	11.12	0.71	16.9	2.9	0.3%
Fort Erie (Anger Ave)	P.	Fc.C.	14.68	0.87	4.7	4.6	0.5%
Grimsby (Baker Road)	C.A.S.	Fe.S.	10.31	0.70	7.1	2.6	0.3%
Halton Hills (Acton)	C.A.S/E.P.	Fc.C.	2.96	0.78	2.4	0.8	0.1%
Halton Hills (Georgetown)	C.A.S/E.P.	Fc.C.	10.03	0.73	9.0	2.7	0.3%
Hamilton (Woodward Ave)	C.A.S.	no	296.73	1.41	31.0	151.8	15.1%
Iroquois WPCP	P.	Fc.C.	3.63	2.68	4.7	3.6	0.4%
Kingston Township WPCP	C.A.S.	Fc.C.	16.14	0.94	6.9	5.5	0.6%
Kingston WPCP	P.	A.	58.72	1.01	3.0	21.7	2.2%
Metro Toronto (Highland Cr.)	C.A.S.	Fe.C.	159.68	0.95	29.3	55.4	5.5%
Metro Toronto (Humber)	C.A.S.	Fe.C.	371.56	1.26	30.3	171.0	17.0%
Metro Toronto (Main)	C.A.S.	Fe.C.	712.84	0.93	29.4	241.9	24.1%
Metro Toronto (North Toronto)	C.A.S.	Fe.C.	35.68	0.96	30.3	12.5	1.2%
Milton WPCP	C.A.S./E.P.	A.	10.05	0.44	2.5	1.6	0.2%
Mississauga (Clarkson)	C.A.S.	Fe.C.	66.17	0.94	18.3	22.0	2.2%
Mississauga (Lakeview)	C.A.S.	Fe.C.	198.69	0.77	29.1	55.9	5.6%
Napanee WPCP	C.A.S.	Fe.C.	5.88	4.08	3.8	8.8	0.9%
Newcastle (Port Darlington)	C.A.S.	A.	6.59	1.42	13.6	3.4	0.3%
Newmarket WPCP	C.A.S./E.P.	--	14.93	0.80	?	4.4	0.4%
Niagara Falls (Stamford)	P.(now RBC)	Fc.C.	53.18	0.78	9.0	15.2	1.5%
Oakville (South East)	C.A.S.	A.	12.19	0.86	2.8	3.8	0.4%
Oakville (Southwest)	C.A.S.	Fc.C.	28.51	1.17	2.7	12.2	1.2%
Orangeville WPCP	C.A.S./E.P.	A.	7.60	0.37	28.2	1.0	0.1%
Oshawa (Harmony Cr. No. 1)	T.F.	A.	27.27	0.98	22.0	9.8	1.0%
Oshawa (Harmony Cr. No.2)	C.A.S.	A.	27.50	0.80	22.0	8.0	0.8%
Peterborough WPCP	C.A.S.	Fe.S.	53.88	0.82	1.0	16.1	1.6%
Pickering (York-Durham)	C.A.S.	A.	97.57	1.30	11.2	46.3	4.6%
Picton WPCP	C.S.	A.	3.4.	0.78	1.0	1.0	0.1%
Port Colborne (Seaway)	C.A.S.	Fc.C.	13.03	0.91	5.6	4.3	0.4%
Port Hope WPCP	H.R.A.S.	A.	8.01	0.64	3.9	1.9	0.2%
Prescott-Edwardsburg WPCP	P.	Fc./P	4.68	0.76	3.4	1.3	0.1%
St. Catharines (Port Dalhousie)	C.A.S.	Fc.C.	36.53	0.55	4.6	7.3	0.7%
St. Catharines (Port Weller)	C.A.S.	A.	37.51	0.69	5.0	9.5	0.9%
Trenton WPCP	C.A.S.	Fe.C.	10.46	0.78	6.3	3.0	0.3%
Welland WPCP	C.A.S.	Fe.C.	38.27	0.69	10.0	9.6	1.0%
Whitby (Corbett Cr.)	C.A.S.	A.	13.09	1.19	9.0	5.7	0.6%
Whitby (Pringle Creek No. 1)	C.A.S.	A.	4.91	0.63	6.7	1.1	0.1%
Whitby (Pringle Creek No. 2)	C.A.S.	A.	6.41	0.93	6.8	2.2	0.2%
N=		45				1004.9	

Notation: see Table A.1.2

Table A.1.2:- Specifications & Performance of Ontario Municipal WWTPs in the Lake Erie Basin.

LAKE ERIE BASIN:

			LONG TERM AVERAGES FROM MOE DATA 1981-85				
PLANT	PLANT TYPE	CHEMICAL	DAILY FLOW m3/day*1000	TOTAL P CONC. mg/L	NUMBER OF SAMPLES PER MONTH 1984-85 average	APPROX. ANNUAL P LOAD tonnes/year	PERCENT TOTAL LOAD %
Adelaide WPCP (London)	C.A.S.	Fs.C.	15.48	0.94	16.58	5.3	2.2%
Amherstburg WPCP	P.	Fc.C.	5.12	2.82	1.00	5.3	2.2%
Belle River-Maidstone WPCP	E.A.	A.	5.83	0.52	6.58	1.1	0.5%
Brantford WPCP	C.A.S.	Fs.C.	50.85	0.78	20.75	14.5	5.9%
Chatham WPCP	C.A.S./E.P.	Fs.C.	26.15	0.83	12.08	7.9	3.2%
Corunna P.V. (Moore)	E.A.	A.	2.05	0.85	1.54	0.6	0.3%
Dresden WPCP	E.A.	A.C.	1.67	0.41	2.13	0.3	0.1%
Dunnville WPCP	C.A.S.	Fs.C.	4.49	0.67	13.29	1.1	0.4%
Fergus WPCP	C.A.S.	Fs.C.	3.42	0.63	32.17	0.8	0.3%
Galt WPCP (Cambridge)	C.A.S.	Fc.C.	31.57	0.86	10.42	9.9	4.0%
Greenway WPCP (London)	C.A.S.	Fs.C.	121.87	0.98	20.38	43.6	17.8%
Guelph WPCP	C.A.S./E.P.	A.	44.45	1.22	18.08	19.8	8.1%
Hespeler WPCP (Cambridge)	H.R.A.S.	Fs./Fc.C.	5.35	0.94	4.03	1.8	0.7%
Ingersoll New WPCP	C.A.S.	Fs.C.	4.30	0.91	1.75	1.4	0.6%
Kitchener WPCP	C.A.S.	Fs.S.	64.95	0.79	14.22	18.7	7.6%
Leamington WPCP	C.A.S.	Fc.C.	7.24	0.87	12.36	2.3	0.9%
Little River WPCP (Windsor)	C.A.S.	A.C.	34.13	0.65	30.25	8.1	3.3%
Oxford WPCP (London)	C.A.S.	Fs.C.	4.82	1.29	14.29	2.3	0.9%
Paris WPCP	E.A.	Fc.C.	2.27	0.95	1.42	0.8	0.3%
Pottersburg WPCP (London)	C.A.S.	Fs.C.	16.78	0.77	17.29	4.7	1.9%
Preston WPCP (Cambridge)	C.A.S.	Fc.C.	7.99	0.72	3.39	2.1	0.9%
Sarnia WPCP	P.	Fc.C.	51.49	0.90	15.67	16.9	6.9%
Simcoe WPCP	C.A.S./E.P.	Fc.C.	9.25	0.58	30.00	2.0	0.8%
St. Thomas WPCP	C.A.S.	A.	21.84	1.15	1.00	9.2	3.7%
Stratford WPCP	C.A.S./E.P.	A.	23.57	0.47	1.82	4.0	1.6%
Tillsonburg WPCP	C.A.S.	A.	5.23	0.61	1.96	1.2	0.5%
Vauxhall WPCP (London)	C.A.S.	L.	19.28	0.83	17.46	5.8	2.4%
Wallaceburg WPCP	C.A.S.	Fc.C.	6.46	0.72	0.96	1.7	0.7%
Waterloo WPCP	C.A.S.	Fs.C.	39.29	0.81	17.67	11.6	4.7%
Westerly WPCP (Windsor)	P.	A.	107.97	0.84	30.25	33.1	13.5%
Woodstock WPCP	C.A.S.	Fc.C.	21.80	0.90	4.50	7.2	2.9%
N=	31					245.2	

NOTATION:

PLANT TYPE:

C.A.S.	Conventional Activated Sludge
C.S.	Contact Stabilization
E.A.	Extended Aeration
E.P.	Effluent Polishing
H.R.A.S.	High Rate Activated Sludge
O.D.	Oxidation Ditch
P.	Primary
T.F.	Trickling Filter

CHEMICAL ADDED:

A.	Alum
A.C.	Aluminum Chloride
Fc.C.	Ferric Chloride
Fs.C.	Ferrous Chloride
Fs.S.	Ferrous Sulphate
L.	Lime
P.	Polymer
no	no chemical added

Table A.1.3:- Specifications & Performance of Ontario Municipal WWTPs in the Upper Great Lakes Basins.

UPPER GREAT LAKES BASINS: PLANT	PLANT TYPE	CHEMICAL	LONG TERM AVERAGES FROM MOE DATA 1981-85 DAILY FLOW m^3/day*1000	TOTAL P CONC. mg/L	NUMBER OF SAMPLES PER MONTH 1984-85 average	APPR. ANNUAL P LOAD tonnes/year	PERCENT TOTAL LOAD %
Barrie WPCP	C.A.S.	A.	24.00	0.89	28.42	7.8	3.1%
Bradford WPCP	C.A.S./E.P.	A./P.	3.18	0.55	4.17	0.6	0.3%
Collingwood WPCP	C.A.S.	A.	16.83	1.50	1.88	9.2	3.6%
Eaton Lake WPCP (Elliot Lake)	C.A.S.	A.	10.40	0.97	12.67	3.7	1.4%
Goderich WPCP	C.A.S.	A.	8.82	1.49	2.00	4.8	1.9%
Hanover WPCP	C.A.S.	A.	3.73	1.09	1.00	1.5	0.6%
Huntsville WPCP	C.A.S.	A.	4.04	0.45	1.14	0.7	0.3%
Midland WPCP	C.A.S.	Fe.C.	9.25	2.85	2.29	9.6	3.8%
Mikkola WPCP (Walden)	E.A.	no	0.96	2.33	1.83	0.8	0.3%
North Bay WPCP	C.A.S.	Fe./Fs.C.	33.91	1.42	3.29	17.6	6.9%
Orillia WPCP	C.A.S.	A.	17.42	0.42	21.30	2.7	1.0%
Owen Sound WPCP	P.	Fe.C.	20.46	0.95	1.78	7.1	2.8%
Parry Sound WPCP	C.A.S.	Fe.C.	4.20	0.86	7.83	1.3	0.5%
Port Elgin WPCP	O.D.	no	3.66	1.91	1.00	2.6	1.0%
Sault Ste. Marie WPCP	P.	no	48.50	3.86	4.38	68.4	26.8%
Sturgeon Falls WPCP	C.A.S.	Fe./Fs.C.	6.47	0.52	1.58	1.2	0.5%
Sudbury WPCP	H.R.A.S.	no	53.01	1.91	2.25	37.0	14.5%
Thunder Bay WPCP	P.	Fe.C.	99.39	2.03	128.63	73.7	28.9%
Valley East WPCP	C.A.S.	Fe./Fs.C.	4.80	1.29	9.71	2.3	0.9%
Walkerton WPCP	C.A.S.	Fe.C.	5.24	1.38	2.25	2.6	1.0%
	N=	20				255.1	

NOTATION:

PLANT TYPE:

C.A.S.	Conventional Activated Sludge
C.S.	Contact Stabilization
E.A.	Extended Aeration
E.P.	Effluent Polishing
H.R.A.S.	High Rate Activated Sludge
O.D.	Oxidation Ditch
P.	Primary
T.F.	Trickling Filter

CHEMICAL TYPE:

A.	Alum
A.C.	Aluminum Chloride
Fe.C.	Ferric Chloride
Fs.C.	Ferrous Chloride
Fs.S.	Ferrous Sulphate
L.	Lime
P.	Polymer
no	no chemical added

Appendix 2

A.2 Comparisons of Sampling Methods for Welland, Waterloo and Galt WWTPs

Sample Calculation: Test of Significance for Differences Between Means for Various Sampling Techniques.

Day:	Influent TP: Galt STP Flow-weighted Composites 24 h (mg/L)	8 h (mg/L)	d	d^2
1/10/86	3.85	3.07	-0.78	0.60
2/10/86	4.87	3.85	-1.02	1.04
3/10/86	6.88	3.93	-2.95	8.70
4/10/86	4.04	3.22	-0.82	0.67
5/10/86	3.85	2.57	-1.27	1.62
6/10/86	4.36	3.74	-0.62	0.39
7/10/86	5.75	6.72	0.97	0.94
			Σ= -6.49	Σ= 13.96

Null Hypothesis(H0):

There is no difference between mean phosphorus concentration based on 24-h flow-weighted composites and the mean based on 8-h flow-weighted composites for influent total phosphorus (listed in Table A.2.1) for the Galt STP.

A paired t-test was used to determine if the differences between the two means was significant as follows:

$$\bar{d} = \Sigma d/n = -6.49/7 = -0.93$$

$$s_d = [(\Sigma d^2 - (\Sigma d)^2/n)/n*(n-1)]^{1/2}$$

$$= [(13.96 - (-6.49)^2/7)/(7*6)]^{1/2} = 0.44$$

$$t = \bar{d}/s_d = 0.93/0.44 = 2.14$$

From statistics tables:

$$t_{95\%,6} = 2.48$$

$$t_{99\%,6} = 3.71$$

Therefore, we accept H0 (ie. that the means for the two compositing procedures are not different) at the 5% and 1% level of significance.

Table A.2.1:- Influent Phosphorus (Welland): Mean Concentrations from Various Sampling Techniques.

Day	Flow-weighted Comp		Volume Composite		Grab Samples			
	24 h	8 h	24h	8h	Max.	Time(h)	Min.	Time(h)
			INFLUENT TP:					
20/8/86	4.94	3.27	4.69	3.24	7.19	1200	2.21	800
21/8/86	3.13	3.18	3.48	3.18	5.94	1200	1.47	1600
22/8/86	4.34	2.61	4.06	2.54	6.95	1400	1.77	800
23/8/86	2.80	3.20	3.14	3.30	5.97	1400	1.75	2200
24/8/86	4.48	3.46	4.44	3.33	6.06	1400	1.83	800
25/8/86	5.29	3.39	5.05	3.41	7.88	1600	2.31	800
26/8/86	4.15	3.63	4.35	3.69	6.52	1200	1.56	2400
AVG	4.16	3.25	4.17	3.24	6.64		1.84	
%DIFF		-22%	0%	-22%	60%		-56%	
DIFF@95%		Yes	No	Yes	Yes		Yes	
DIFF@99%		No	No	No	Yes		Yes	
			INFLUENT SOL. P:					
20/8/86	2.16	1.95	2.19	1.97	2.93	200	0.26	1200
21/8/86	1.64	1.78	1.87	1.81	3.20	1200	0.67	1600
22/8/86	2.49	1.62	2.36	1.57	3.60	2200	1.07	800
23/8/86	1.54	2.29	1.90	2.34	3.60	200	0.53	1800
24/8/86	2.52	1.89	2.58	1.81	4.00	2400	0.67	1200
25/8/86	2.59	2.30	2.54	2.29	3.60	1400	1.00	1800
26/8/86	1.41	2.31	1.79	2.37	3.20	200	0.93	2000
AVG	2.05	2.02	2.18	2.02	3.45		0.73	
%DIFF		-1%	6%	-1%	68%		-64%	
DIFF@95%		No	No	No	Yes		Yes	
DIFF@99%		No	No	No	Yes		Yes	

Table A.2.2:- Effluent Phosphorus (Welland): Mean Concentrations from Various Sampling Techniques.

Day	Flow-weighted Comp		Volume Composite		Grab Samples			
	24 h	8 h	24h	8h	Max.	Time(h)	Min.	Time(h)
			EFFLUENT TP:					
20/6/86	0.97	0.90	0.96	0.90	1.23	2000	0.82	800
21/8/86	0.92	0.87	0.91	0.88	1.02	1800	0.83	1000
22/8/86	0.83	0.84	0.84	0.84	0.94	2200	0.74	1400
23/8/86	0.96	0.92	0.94	0.93	1.08	1400	0.83	2200
24/8/86	0.85	0.83	0.85	0.83	0.95	1400	0.81	800
25/8/86	1.10	0.94	1.11	0.95	1.87	1600	0.84	800
26/8/86	1.07	1.26	1.12	1.31	1.64	1200	0.88	2400
AVG	0.96	0.94	0.96	0.95	1.25		0.82	
%DIFF		-2%	0%	-1%	30%		-14%	
DIFF@95%		No	No	No	Yes		Yes	
DIFF@99%		No	No	No	No		Yes	
			EFFLUENT SOL. P:					
20/8/86	0.52	0.46	0.53	0.47	0.70	2200	0.40	1600
21/8/86	0.59	0.58	0.59	0.58	0.63	200	0.53	1000
22/8/86	0.57	0.55	0.56	0.56	0.73	1800	0.50	2400
23/8/86	0.50	0.48	0.51	0.49	0.70	2400	0.40	1000
24/8/86	0.59	0.60	0.59	0.60	0.67	400	0.53	1400
25/8/86	0.58	0.58	0.59	0.58	0.77	1800	0.50	1400
26/8/86	0.69	0.65	0.70	0.63	1.13	2400	0.53	1400
27/8/86	0.65	0.81	0.71	0.82	0.87	200	0.53	2400
28/8/86	0.39	0.39	0.38	0.38	0.57	200	0.30	800
AVG	0.60	0.61	0.61	0.61	0.79		0.50	
%DIFF		2%	2%	2%	32%		-16%	
DIFF@95%		No	No	No	Yes		Yes	
DIFF@99%		No	No	No	Yes		Yes	

Table A.2.3:- Influent Phosphorus (Waterloo): Mean Concentrations from Various Sampling Techniques.

Day:	Flow-weighted Comp		Volume Composite		Grab Samples			
	24 h	8 h	24h	8h	Max.	Time(h)	Min.	Time(h)
			INFLUENT TP:					
3/7/86	5.82	5.02	5.30	4.66	7.23	1000	2.63	400
4/7/86	6.56	6.96	6.40	6.54	10.50	1000	2.43	600
5/7/86	5.71	4.60	5.44	4.39	7.23	1200	2.44	600
6/7/86	5.46	4.15	5.19	3.97	7.18	1200	2.41	600
7/7/86	6.03	4.83	5.61	4.35	7.70	1000	2.31	600
8/7/86	6.01	4.65	5.75	4.32	7.46	2400	2.28	600
9/7/86	5.91	4.95	5.69	4.65	7.40	1200	2.44	600
AVG	5.93	5.02	5.67	4.70	7.81		2.42	
%DIFF		-15%	-4%	-21%	32%		-59%	
DIFF@95%		Yes	Yes	Yes	Yes		Yes	
DIFF@99%		No	Yes	Yes	Yes		Yes	
			INFLUENT SOL. P:					
3/7/86	2.84	2.56	2.75	2.37	4.92	2000	1.08	400
4/7/86	2.66	2.74	2.55	2.55	4.46	1600	0.77	2400
5/7/86	3.09	2.71	2.99	2.58	4.00	1000	1.38	600
6/7/86	2.87	2.11	2.73	2.00	3.34	2200	1.08	200
7/7/86	3.25	1.53	2.93	1.38	6.15	2000	0.92	04,06,240
8/7/86	2.56	2.45	2.49	2.25	4.00	2200	0.92	400
9/7/86	2.48	2.19	2.37	1.97	3.84	1000	0.62	400
AVG	2.82	2.33	2.69	2.16	4.42		0.97	
%DIFF		-18%	-5%	-24%	57%		-66%	
DIFF@95%		No	Yes	Yes	Yes		Yes	
DIFF@99%		No	Yes	No	Yes		Yes	

Table A.2.4:- Effluent Phosphorus (Waterloo): Mean Concentrations from Various Sampling Techniques.

Day	Flow-weighted Comp		Volume Composite		Grab Samples			
	24 h	8 h	24h	8h	Max.	Time(h)	Min.	Time(h)
			EFFLUENT TP:					
3/7/86	0.96	1.00	0.96	1.00	1.10	800	0.87	2400
4/7/86	0.89	0.79	0.90	0.79	1.17	2000	0.30	1200
5/7/86	1.05	1.02	1.05	1.02	1.24	2200	0.89	800
6/7/86	1.15	1.07	1.15	1.07	1.62	1800	0.98	2400
7/7/86	1.88	1.51	1.78	1.39	2.46	2200	1.01	200
8/7/86	1.79	2.02	1.81	2.02	2.10	02,1600	1.09	2400
9/7/86	0.78	0.91	0.79	0.93	1.05	200	0.58	2400
AVG	1.21	1.19	1.21	1.18	1.53		0.82	
%DIFF		-2%	-1%	-3%	26%		-33%	
DIFF@95%		No	No	No	Yes		Yes	
DIFF@99%		No	No	No	Yes		No	
			EFFLUENT SOL. P:					
3/7/86	0.41	0.50	0.42	0.51	0.62	600	0.27	1600
4/7/86	0.44	0.36	0.45	0.37	0.65	2400	0.31	1000
5/7/86	0.47	0.45	0.47	0.45	0.62	1800	0.38	10,1200
6/7/86	0.61	0.51	0.61	0.52	0.92	16,1800	0.46	800
7/7/86	1.20	0.97	1.13	0.89	1.58	2400	0.62	04,0600
8/7/86	1.20	1.48	1.23	1.50	1.69	400	0.62	2400
9/8/86	0.27	0.34	0.28	0.35	0.50	200	0.15	2200
AVG	0.66	0.66	0.65	0.65	0.94		0.40	
%DIFF		0%	-0%	-0%	43%		-39%	
DIFF@95%		No	No	No	Yes		Yes	
DIFF@99%		No	No	No	Yes		No	

Table A.2.5:- Influent Phosphorus (Galt): Mean Concentrations from Various Sampling Techniques.

Day	Flow-weighted Comp		Volume Composite		Grab Samples			
	24 h	8 h	24h	8h	Max.	Time(h)	Min.	Time(h)
			INFLUENT TP:					
1/10/86	3.85	3.07	3.67	2.91	6.20	2000	1.42	600
2/10/86	4.87	3.85	4.68	3.67	7.17	1800	1.66	600
3/10/86	6.88	3.93	6.53	3.64	26.10	1400	2.04	400
4/10/86	4.04	3.22	3.78	3.02	6.50	1200	1.37	600
5/10/86	3.85	2.57	3.57	2.43	6.29	1200	1.38	600
6/10/86	4.36	3.74	4.06	3.21	6.07	800	1.21	600
7/10/86	5.75	6.72	5.85	6.83	13.60	600	2.47	400
AVG	4.80	3.87	4.59	3.67	10.28		1.65	
%DIFF		-19%	-4%	-23%	114%		-66%	
DIFF@95%		No	Yes	Yes	No		Yes	
DIFF@99%		No	Yes	No	No		Yes	
			INFLUENT SOL. P:					
1/10/86	2.56	1.98	2.46	1.93	4.50	2000	1.00	600
2/10/86	2.71	2.18	2.64	2.13	4.28	1800	1.07	600
3/10/86	3.60	2.10	3.33	1.91	7.14	1800	0.80	400
4/10/86	2.81	2.19	2.65	2.04	4.55	1000	0.51	400
5/10/86	2.99	2.04	2.78	1.93	5.18	1200	0.98	800
6/10/86	2.70	2.18	2.51	1.88	3.69	2000	0.73	600
7/10/86	2.75	1.94	2.58	1.75	3.88	1200	0.14	600
AVG	2.88	2.09	2.71	1.94	4.75		0.75	
%DIFF		-27%	-6%	-33%	65%		-74%	
DIFF@95%		Yes	Yes	Yes	Yes		Yes	
DIFF@99%		Yes	Yes	Yes	Yes		Yes	

Table A.2.6:- Effluent Phosphorus (Galt): Mean Concentrations from Various Sampling Techniques.

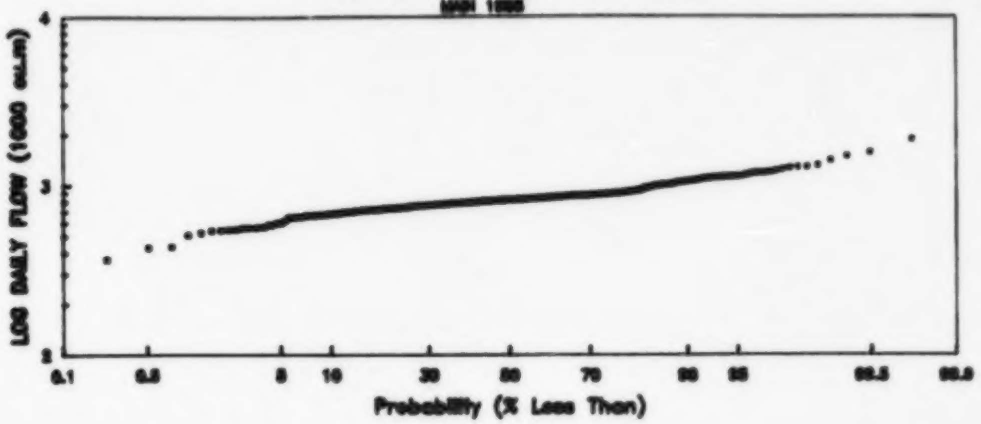
Day	Flow-weighted Comp 24 h	Flow-weighted Comp 8 h	Volume Composite 24h	Volume Composite 8h	Grab Samples Max.	Grab Samples Time(h)	Grab Samples Min.	Grab Samples Time(h)
			EFFLUENT TP:					
1/10/86	1.24	0.99	1.22	0.98	1.57	2200	0.86	800
2/10/86	1.56	1.26	1.52	1.25	1.91	2200	1.12	800
3/10/86	1.69	1.31	1.64	1.30	2.07	2000	1.10	800
4/10/86	1.66	1.42	1.60	1.41	2.11	1600	1.09	1000
5/10/86	1.36	1.18	1.33	1.18	1.59	1800	0.97	1000
6/10/86	1.50	1.18	1.45	1.17	1.79	2000	1.09	600
7/10/86	1.[illegible]8	1.22	1.46	1.22	1.85	2200	1.09	1000
AVG	1.50	1.22	1.46	1.22	1.84		1.05	
%DIFF		-18%	-2%	-19%	23%		-30%	
DIFF@95%		Yes	Yes	Yes	Yes		Yes	
DIFF@99%		Yes	Yes	Yes	Yes		Yes	
			EFFLUENT SOL. P:					
1/10/86	0.28	0.20	0.28	0.21	0.46	2400	0.14	600
2/10/86	0.42	0.30	0.40	0.30	0.68	1800	0.18	1000
3/10/86	0.37	0.24	0.36	0.24	0.62	2200	0.15	1000
4/10/86	0.28	0.42	0.30	0.40	0.87	200	0.14	1000
5/10/86	0.15	0.10	0.14	0.10	0.21	1600	0.03	800
6/10/86	0.32	0.17	0.31	0.18	0.60	2200	0.13	800
7/10/86	0.28	0.28	0.29	0.29	0.50	200	0.17	800
AVG	0.30	0.24	0.30	0.25	0.56		0.13	
%DIFF		-19%	-2%	-19%	87%		-55%	
DIFF@95%		No	No	No	Yes		Yes	
DIFF@99%		No	No	No	Yes		Yes	

Appendix 3

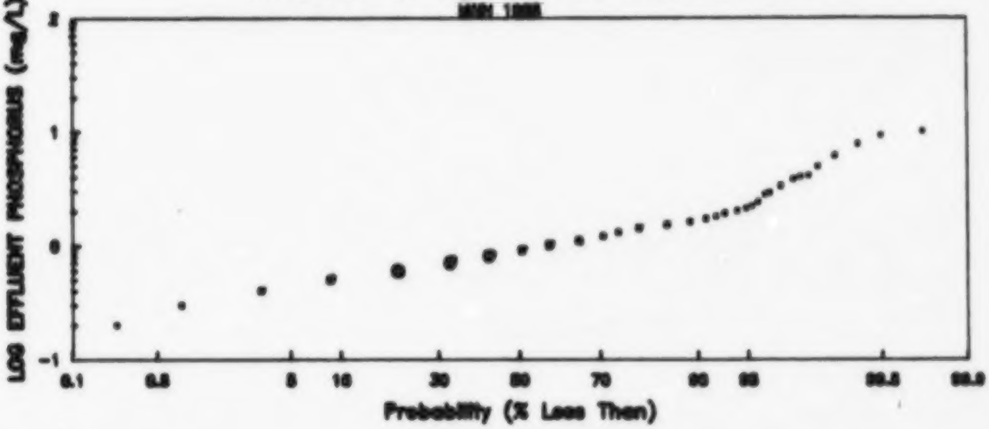
A.3 Probability Plots for Effluent Data for the Main, Humber and Highland Creek WWTPs

Figure A.3.1:- Probability Plots for 1985 Data for the Main WWTP.

PROBPLOT OF log DAILY FLOWS



PROBPLOT OF log EFFLUENT PHOSPHORUS



PROBPLOT OF log EFFLUENT SS

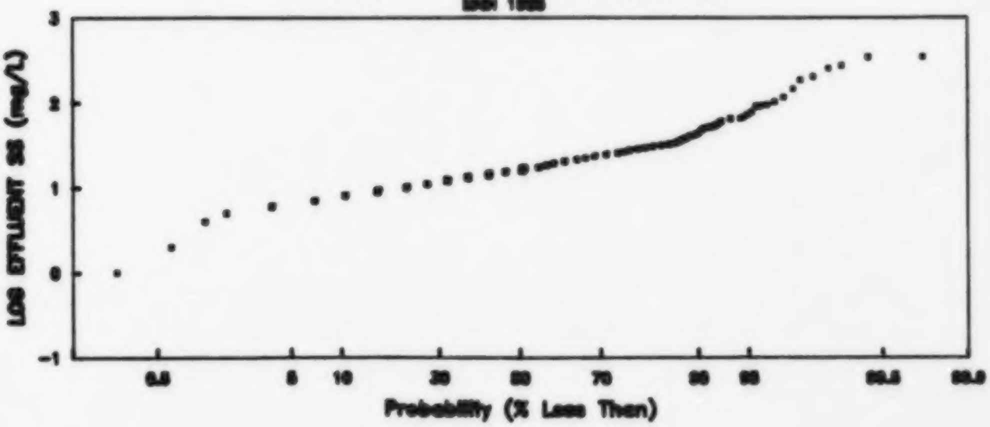
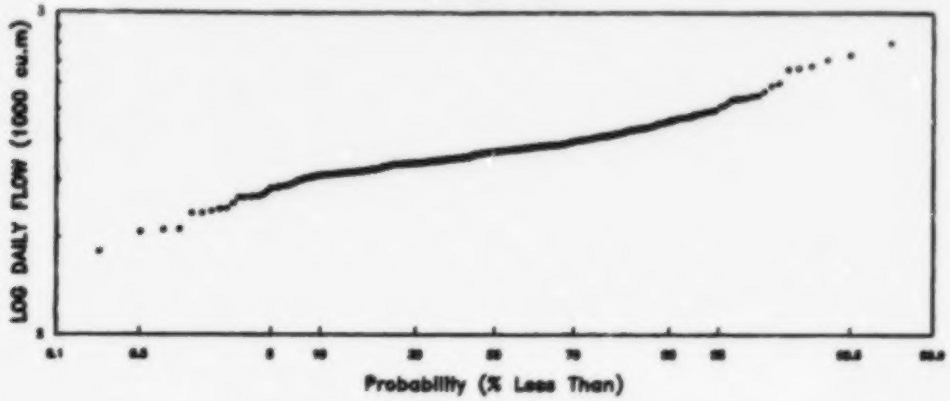
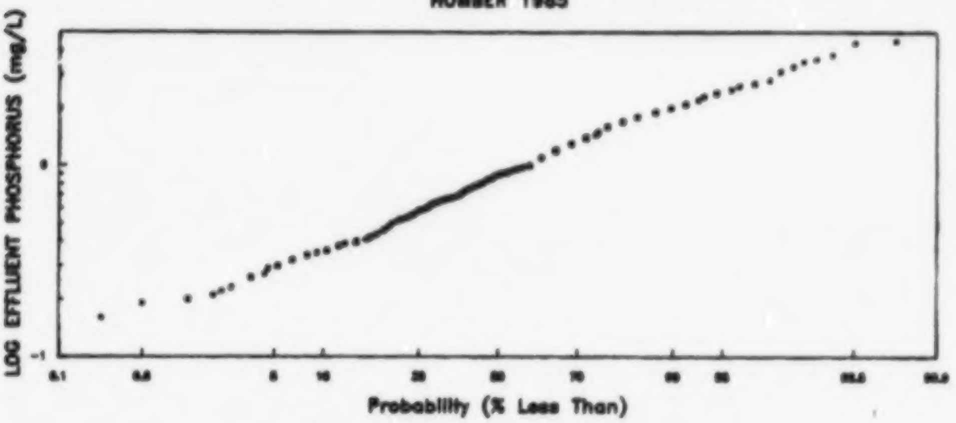


Figure A.3.2:- Probability Plots for 1985 Data for the Humber WWTP.

PROBPLOT OF log DAILY FLOWS
HUMBER 1985



PROBPLOT OF log EFFLUENT PHOSPHORUS
HUMBER 1985



PROBPLOT OF log EFFLUENT SS
HUMBER 1985

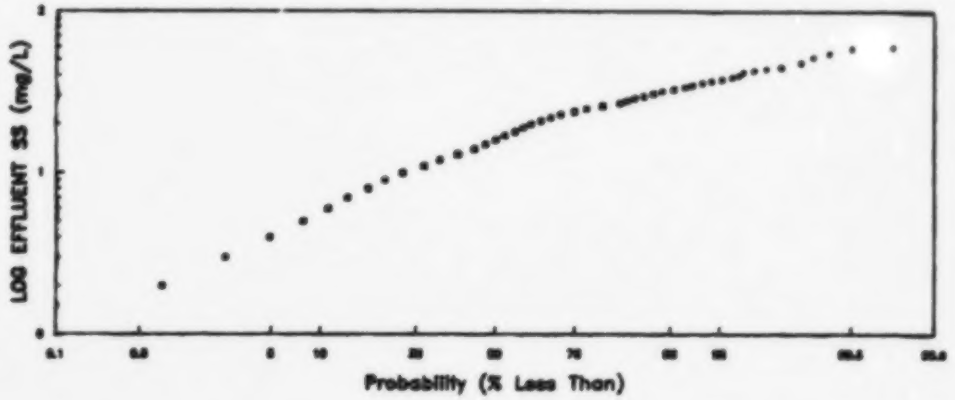
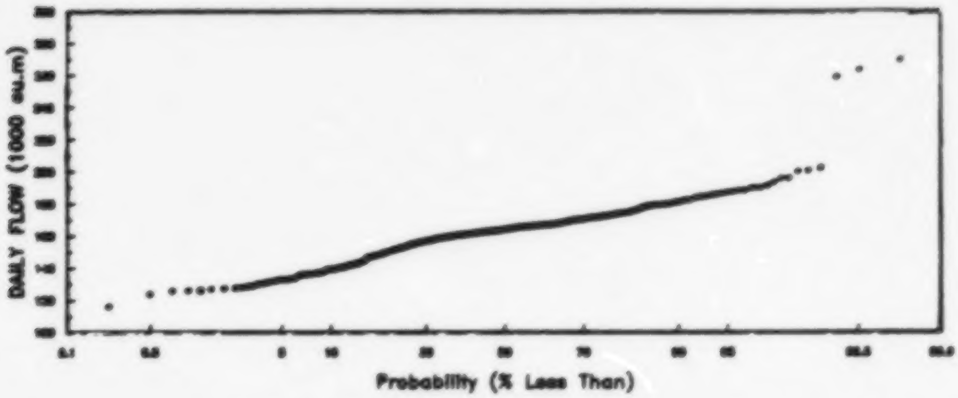
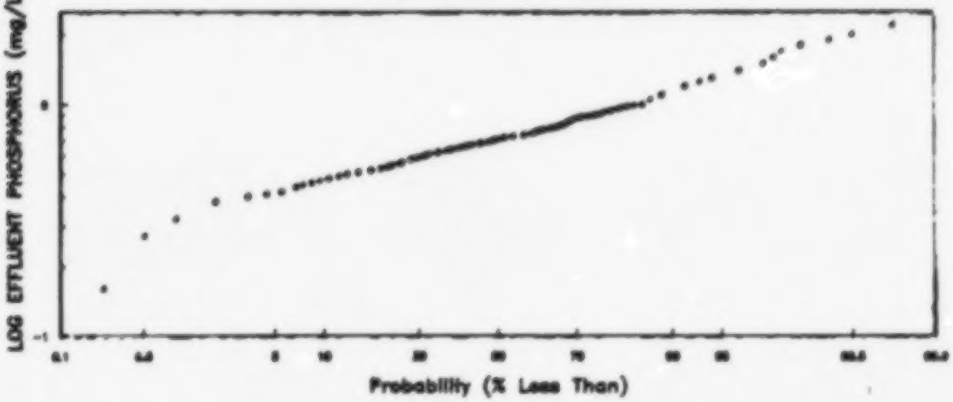
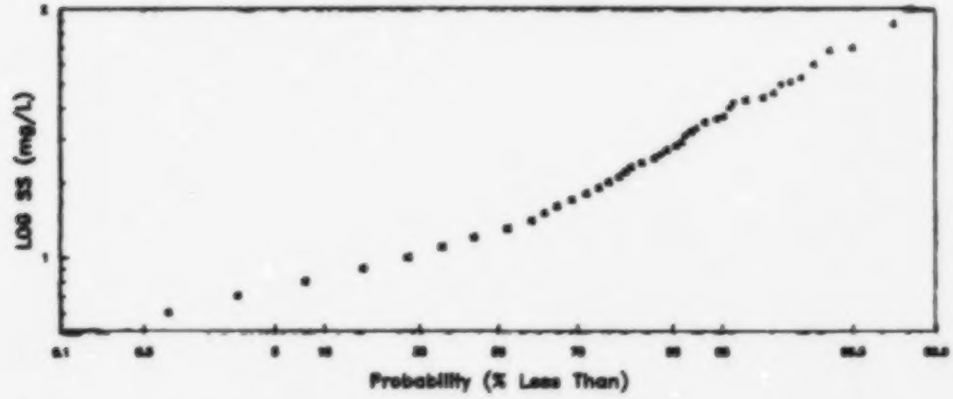


Figure A.3.3:- Probability Plots for 1985 Data for the Highland Creek WWTP.


PROBPLOT OF DAILY FLOWS
HIGHLAND CREEK 1985


PROBPLOT OF log EFFLUENT PHOSPHORUS
HIGHLAND CREEK 1985


PROBPLOT OF log SS
HIGHLAND CREEK 1985

Appendix 4

A.4 Monthly Statistics for Effluent Data for the Main, Humber and Highland Creek WWTPs

Table A.4.1:- Monthly Statistics for 1985 Data for Main WWTP.

Month	FLOW (1000 m3/d)			TP CONC. (mg/L)			TP LOAD (kg/d)		
	Mean	Std. dev.	C.V.	Mean	Std. dev.	C.V.	Mean	Std. dev.	C.V.
JAN.	822.5	125.4	0.15	1.142	0.412	0.36	947.1	296.8	0.31
FEB.	867.3	220.1	0.25	1.132	1.261	1.11	1188.2	1691.7	1.42
MAR.	931.2	134.4	0.14	0.843	0.741	0.88	876.6	887.6	1.01
APR.	872.4	107.3	0.12	0.634	0.132	0.21	549.7	122.6	0.22
MAY	858.7	96.2	0.11	0.940	0.299	0.32	813.6	299.9	0.37
JUN.	829.9	85.3	0.10	1.240	0.607	0.49	1056.6	688.5	0.65
JUL.	753.2	120.6	0.16	1.060	0.388	0.37	816.1	359.5	0.44
AUG.	764.9	218.4	0.29	0.872	0.370	0.42	670.1	344.3	0.51
SEP.	819.1	117.3	0.14	0.757	0.625	0.83	621.7	516.4	0.83
OCT.	765.4	120.3	0.16	2.506	2.479	0.99	2124.7	2553.4	1.20
NOV.	1026.5	214.5	0.21	1.132	0.455	0.40	1198.1	684.4	0.57
DEC.	832.1	93.0	0.11	1.140	0.303	0.27	935.5	276.7	0.30
MIN.	753.2		0.10	0.634		0.21	549.7		0.22
MAX.	1026.5		0.29	2.506		1.11	2124.7		1.42

Table A.4.2:- Monthly Statistics for 1985 Log-Transformed Data for Main WWTP.

Month	FLOW (1000 m3/d) Geo. Mean	FLOW (1000 m3/d) D.F.	TP CONC. (mg/L) Geo. Mean	TP CONC. (mg/L) D.F.	TP LOAD (kg/d) Geo. Mean	TP LOAD (kg/d) D.F.
JAN.	814.2	1.15	1.088	1.365	909.0	1.32
FEB.	844.5	1.25	0.837	1.975	715.4	2.29
MAR.	922.2	1.15	0.688	1.778	654.2	1.97
APR.	866.5	1.12	0.620	1.257	537.0	1.24
MAY	854.1	1.10	0.884	1.475	755.5	1.50
JUN.	825.8	1.10	1.150	1.441	954.5	1.48
JUL.	743.4	1.18	0.995	1.437	740.0	1.57
AUG.	732.6	1.35	0.809	1.472	592.4	1.65
SEP.	810.8	1.15	0.651	1.612	528.2	1.64
OCT.	756.4	1.16	1.816	2.122	1373.3	2.32
NOV.	1008.2	1.20	1.049	1.496	1059.2	1.60
DEC.	827.1	1.11	1.100	1.323	897.7	1.33
MIN.	732.6	1.10	0.620	1.257	528.2	1.24
MAX.	1008.2	1.35	1.816	2.122	1373.3	2.32

Table A.4.3:- Monthly Statistics for 1985 Data for Humber WWTP.

	FLOW (1000 m3/d)			TP CONC. (mg/L)			TP-LOAD (kg/d)		
Month:	Mean	Std. dev.	C.V.	Mean	Std. dev.	C.V.	Mean	Std. dev.	C.V.
JAN.	360.5	26.4	0.07	1.462	0.781	0.53	534.0	298.8	0.56
FEB.	414.1	122.4	0.30	1.130	0.581	0.51	461.2	266.8	0.58
MAR.	385.2	84.6	0.22	1.169	0.457	0.39	452.7	213.6	0.47
APR.	354.7	58.0	0.16	0.918	0.555	0.60	319.0	182.7	0.57
MAY	332.6	47.3	0.14	0.902	0.401	0.44	299.0	135.5	0.45
JUN.	332.5	68.2	0.21	1.725	0.815	0.47	605.7	376.7	0.62
JUL.	369.7	40.8	0.11	1.385	0.682	0.49	507.6	233.9	0.46
AUG.	387.4	89.0	0.23	0.658	0.504	0.77	241.3	178.7	0.74
SEP.	403.7	56.3	0.14	0.866	0.594	0.69	355.4	244.5	0.69
OCT.	361.9	35.1	0.10	1.435	1.158	0.81	527.1	446.5	0.85
NOV.	463.2	82.3	0.18	0.582	0.278	0.48	271.6	146.8	0.54
DEC.	366.4	57.0	0.16	0.650	0.317	0.49	234.6	114.1	0.49
MIN.	332.5		0.07	0.582		0.39	234.6		0.45
MAX.	463.2		0.30	1.725		0.81	605.7		0.85

Table A.4.4:- Monthly Statistics for 1985 Log-Transformed Data for Humber WWTP.

Month	FLOW (1000 m3/d) Geo. Mean	FLOW (1000 m3/d) D.F.	TP CONC. (mg/L) Geo. Mean	TP CONC. (mg/L) D.F.	TP LOAD (kg/d) Geo. Mean	TP LOAD (kg/d) D.F.
JAN.	359.5	1.08	1.265	1.75	454.8	1.81
FEB.	400.6	1.28	0.974	1.791	388.5	1.85
MAR.	377.8	1.21	1.07	1.577	404.4	1.65
APR.	350.4	1.17	0.775	1.82	271.5	1.81
MAY	329.2	1.16	0.82	1.572	269.9	1.61
JUN.	324.7	1.27	1.524	1.707	488.9	2.03
JUL.	367.6	1.12	1.219	1.704	448.2	1.72
AUG.	377.7	1.26	0.521	1.966	196.9	1.86
SEP.	400.2	1.14	0.672	2.134	267.4	2.28
OCT.	360.3	1.1	1.091	2.116	393.1	2.17
NOV.	456.8	1.18	0.527	1.568	240.6	1.64
DEC.	362.0	1.18	0.584	1.598	211.2	1.58
MIN.	324.7	1.08	0.521	1.568	196.9	1.58
MAX.	456.8	1.28	1.524	2.134	488.9	2.28

Table A.4.5:- Monthly Statistics for 1985 Data for Highland Creek WWTP.

Month	FLOW (1000 m3/d)			TP CONC. (mg/L)			TP-LOAD (kg/d)		
	Mean	Std. dev.	C.V.	Mean	Std. dev.	C.V.	Mean	Std. dev.	C.V.
JAN.	137.5	7.12	0.05	0.790	0.263	0.33	108.8	37.6	0.35
FEB.	148.8	35.30	0.24	0.801	0.230	0.29	115.5	39.2	0.34
MAR.	162.7	13.00	0.08	0.637	0.228	0.36	103.1	36.8	0.36
APR.	161.7	9.33	0.06	0.931	0.210	0.23	150.1	32.4	0.22
MAY	161.5	8.80	0.05	0.694	0.158	0.23	112.3	26.9	0.24
JUN.	167.7	9.00	0.05	0.547	0.083	0.15	91.6	13.8	0.15
JUL.	170.5	8.75	0.05	0.793	0.185	0.23	135.1	32.2	0.24
AUG.	176.3	11.00	0.06	0.920	0.329	0.36	162.4	59.5	0.37
SEP.	172.5	13.07	0.08	0.573	0.174	0.30	99.1	30.4	0.31
OCT.	166.2	7.98	0.05	0.907	0.372	0.41	152.0	66.9	0.44
NOV.	174.3	19.60	0.11	0.890	0.446	0.50	151.9	73.7	0.49
DEC.	159.1	10.00	0.06	0.700	0.312	0.45	111.6	52.8	0.47
MIN.	137.5		0.05	0.547		0.15	91.6		0.15
MAX.	176.3		0.24	0.931		0.50	162.4		0.49

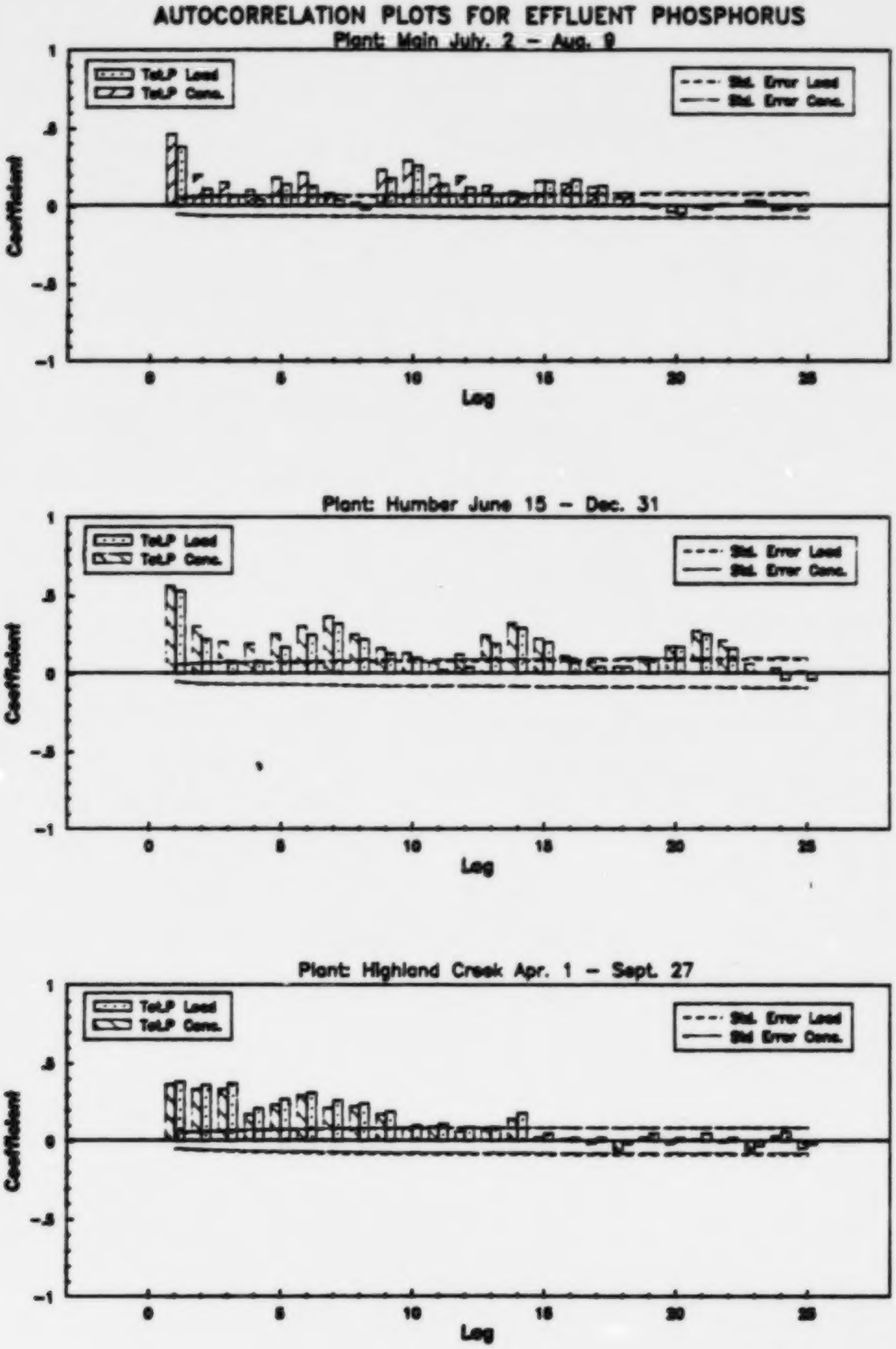
Table A.4.6:- Monthly Statistics for 1985 Log-Transformed Data for Highland Creek WWTP.

Month	FLOW (1000 m3/d)		TP CONC. (mg/L)		TP LOAD (kg/d)	
	Geo. Mean	D.F.	Geo. Mean	D.F.	Geo. Mean	D.F.
JAN.	137.3	1.05	0.754	1.353	103.3	1.38
FEB.	145.8	1.21	0.771	1.323	110.0	1.36
MAR.	162.2	1.08	0.606	1.355	98.3	1.34
APR.	161.4	1.06	0.909	1.246	146.8	1.24
MAY	161.3	1.06	0.675	1.278	108.9	1.30
JUN.	167.5	1.06	0.541	1.156	90.6	1.15
JUL.	170.3	1.05	0.775	1.231	132.0	1.24
AUG.	175.9	1.07	0.861	1.464	151.4	1.48
SEP.	172.0	1.08	0.551	1.321	95.3	1.32
OCT.	166.0	1.05	0.848	1.433	140.9	1.46
NOV.	173.4	1.10	0.797	1.616	136.5	1.60
DEC.	158.8	1.07	0.644	1.532	102.2	1.54
MIN.	137.3	1.05	0.541	1.156	90.6	1.15
MAX.	175.9	1.21	0.909	1.616	151.4	1.60

Appendix 5

A.5 Autocorrelograms for Phosphorus Concentrations and Loads for the Main, Humber and Highland Creek WWTPs

Figure A.5.1:- Autocorrelograms for Phosphorus Concentrations and Loads for the Main, Humber and Highland Creek WWTPs.



Appendix 6

A.6 Precisions for Monthly Mean Values for the Main, Humber and Highland Creek WWTPs

Table A.6.1:- Precision for Annual and Monthly Means for 1985 TP Load Data for the Main WWTP.

Period	TP LOAD (kg/d): Mean (kg/d)	C.V.	N	Precision (kg/d)	Precision (%)
YEAR	983.4	1.10	333	116.92	12%
JAN.	947.1	0.31	26	119.91	13%
FEB.	1188.2	1.42	21	770.07	65%
MAR.	876.6	1.01	27	351.20	40%
APR.	549.7	0.22	29	46.63	8%
MAY	813.6	0.37	30	111.97	14%
JUN.	1056.6	0.65	29	261.84	25%
JUL.	816.1	0.44	30	134.22	16%
AUG.	670.1	0.51	29	130.94	20%
SEP.	621.7	0.83	30	192.81	31%
OCT.	2124.7	1.20	31	936.47	44%
NOV.	1198.1	0.57	27	270.80	23%
DEC.	935.5	0.29	24	113.06	12%
MIN.	549.7	0.22		46.63	8%
MAX.	2124.7	1.42		936.47	65%

Precision = t95% *(st dev/SQR N) MEAN = 26%

Table A.6.2:- Precision for Annual and Monthly Means for 1985 TO Load Data for the Humber WWTP.

Period	TP LOAD (kg/d): Mean (kg/d)	C.V.	N	Precision (kg/d)	Precision (%)
YEAR	393.8	0.70	350	28.82	7%
JAN.	534.0	0.56	31	109.59	21%
FEB.	461.2	0.58	26	107.79	23%
MAR.	452.7	0.47	31	78.34	17%
APR.	319.0	0.57	30	68.21	21%
MAY	299.0	0.45	31	49.70	17%
JUN.	605.7	0.62	19	181.57	30%
JUL.	507.6	0.46	31	85.78	17%
AUG.	241.3	0.74	31	65.54	27%
SEP.	355.4	0.69	28	94.82	27%
OCT.	527.1	0.85	31	163.76	31%
NOV.	271.6	0.54	30	54.81	20%
DEC.	234.6	0.49	31	41.85	18%
MIN.	0.6	0.39		41.85	17%
MAX.	1.7	0.81		181.57	31%

Precision = t95% *(st dev/SQR N)   MEAN = 22%

Table A.6.3:- Precision for Annual and Monthly Means for 1985 TP Load Data for the Highland Creek WWTP.

Period	TP LOAD (kg/d): Mean (kg/d)	C.V.	N	Precision (kg/d)	Precision (%)
YEAR	124.6	0.40	354	5.24	4%
JAN.	108.8	0.35	30	14.04	13%
FEB.	115.5	0.34	27	15.51	13%
MAR.	103.1	0.36	29	14.00	14%
APR.	150.1	0.22	30	12.10	8%
MAY	112.3	0.24	31	9.87	9%
JUN.	91.6	0.15	30	5.15	6%
JUL.	135.1	0.24	31	11.81	9%
AUG.	162.4	0.37	31	21.82	13%
SEP.	99.1	0.31	27	12.03	12%
OCT.	152.0	0.44	30	24.98	16%
NOV.	151.9	0.49	27	29.16	19%
DEC.	111.6	0.47	31	19.36	17%
MIN.	0.5	0.15		5.15	8%
MAX.	0.9	0.50		29.16	19%

Precision = t95% *(st dev/SQR N)   MEAN =   12%

Appendix 7

A.7 Procedure for Estimating Precisions for Basin-Wide Estimates

Procedure for Estimating Precisions for Basin Wide Estimates

The step-by-step procedure for developing precision estimates for the basin-wide phosphorus loads and aggregate average phosphorus concentrations is given as follows:

1.) For 1984 and 1985 for each of the WWTPs in the Lake Erie and Lake Ontario Basins, the annual mean flow rate, the annual mean effluent phosphorus concentration and the number of effluent phosphorus samples collected during the year were entered into a Lotus spreadsheet. This information was obtained from the Phase 1 report, "Phosphorus Removal Upgrading at Wastewater Treatment Plants in the Great Lakes Basin" (Canviro, 1988a) and binders of information collected by Canviro Consultants for the report.

2.) For the three Metro Toronto WWTPs, it was observed that effluent phosphorus variability tended to increase as level increased. This can be seen from the values for the means and standard deviations for the three WWTPs listed in Table 5.4. This basic observation was used to predict the standard deviation of the effluent phosphorus concentration when the annual mean was known. Two alternative procedures were employed. Method #1 was based on the average coefficient of variation:

$$(sp)i = \overline{c.v.} * \overline{C}_i \quad \text{.................................} \quad [A.1]$$

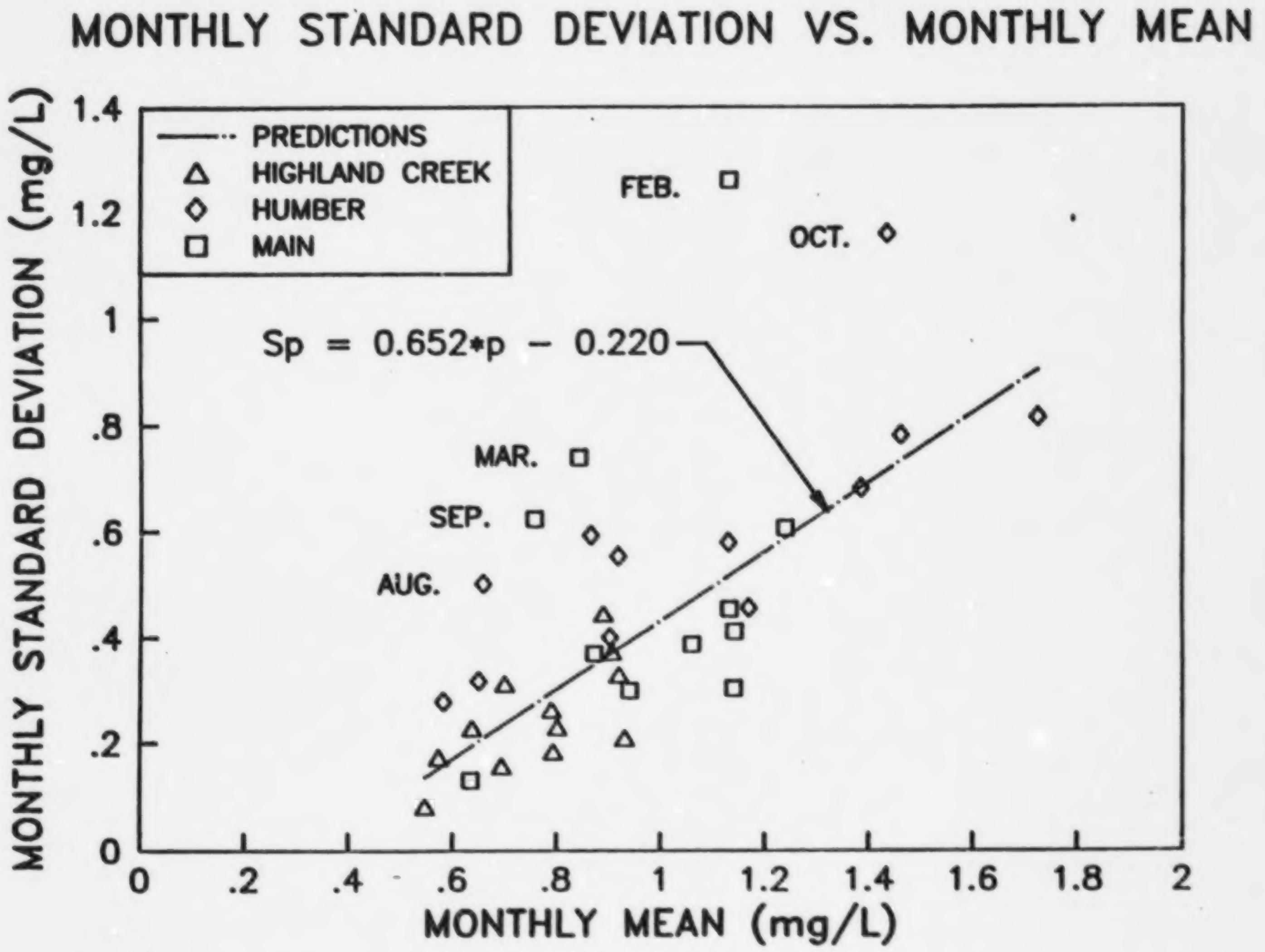
where: $(sp)i$ = the standard deviation of effluent phosphorus concentration at WWTP i,

$\overline{c.v.}$ = the average coefficient of variation for effluent phosphorus for the Main, Humber and Highland Creek WWTPs
= $(0.91+0.67+0.38)/3 = 0.65$

$\overline{C}_i$ = the annual mean effluent phosphorus concentration at WWTP i.

An alternative to equation A.1 was developed based on regression procedures. For the three Metro Toronto WWTPs, the monthly standard deviations for effluent phosphorus concentration were regressed against the monthly mean effluent phosphorus concentration. Because several of the months (Sep., Mar., and Feb. for Main; Aug. and Oct. for Humber) had much higher standard deviations, these months were given a weighting which was one-tenth that for other months. The data and the fitted regression line are given in Fig. A.7.1. The correlation coefficient for the weighted regression was 0.82. Therefore, for Method #2 the relationship between standard deviation and mean was:

Figure A.7.1


MONTHLY STANDARD DEVIATION VS. MONTHLY MEAN
PREDICTIONS
HIGHLAND CREEK
HUMBER
MAIN
FEB.
OCT.
MAR.
SEP.
AUG.
Sp = 0.652*p − 0.220
MONTHLY STANDARD DEVIATION (mg/L)
0
.2
.4
.6
.8
1
1.2
1.4
MONTHLY MEAN (mg/L)
0
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2

$(sp)_i = b*\bar{C}_i - m$ ....[A.2]

where: $(sp)_i$, $\bar{C}_i$ = as defined for equation A.1

b,m = regression coefficients, b = 0.65, m = 0.22

3.) Based on the results from the three Metro Toronto WWTPs and assumptions regarding the nature of the serial correlation for effluent suspended solids data, a relationship was developed between the number of phosphorus samples in a year (n) and the value of correction factor (C.F.). It was assumed that the time dependence for the phosphorus concentration could be modeled using a simple Markov (or first-order autoregressive) model. Sanders et al. (1987) have observed that this type of structure frequently applies for water quality data. For this model, the autocorrelation coefficient at lag 1 is used to define all values at other lags as follows (Sanders et al., 1987):

$r(k) = r(1)^k$ ....[A.3]

Median r(1) values for effluent phosphorus concentrations were 0.46 (Main), 0.56 (Humber), and 0.36 (Highland Creek). Using equations A.3 and 8.2, correction factors were calculated for r(1) values of 0.4, 0.5, and 0.6. Sample autocorrelation coefficients were only included in the equation 8.2 provided that they were significant (see equation 8.3). The results are summarized as follows:

Sampling Frequency	No. of Samples (N) Per Year		C.F.:	
		r(1)=0.4	r(1)=0.5	r(1)=0.6
daily	365	1.46	1.66	1.83
every other day	182	1.13	1.22	1.31

Accordingly, based on the above assumptions corrections for serial correlation were only applied provided that the WWTP collected more that 182 samples per year. If the WWTP collected between 182 and 365 samples per year then linear interpolation was employed to obtain an estimate of the C.F. The results are summarized as follows:

for $N < 182$: C.F. = 1.00 ....[A.4.1]

for $N > 182$:

& $r(1) = 0.4$: C.F. = $0.0018*N + 0.804$ .... [A.4.2]

& $r(1) = 0.5$: C.F. = $0.0024*N + 0.789$ .... [A.4.3]

& $r(1) = 0.6$: $C.F. = 0.0029*N + 0.789$ .... [A.4.4]

4.) Using the relationships developed in steps (2) & (3) and the mean annual effluent phosphorus concentration and sampling frequency at each WWTP, the standard error of the mean annual effluent phosphorus concentration was calculated as follows in the spreadsheet:

$s.e.(\bar{C}_i) = (sp)_i*(C.F.)_i/(N_i)^{1/2}$ ....[A.5]

where: $s.e.(\bar{C}_i)$ = the standard error of the annual mean TP concentration at WWTP i,

$(sp)_i$ = estimated standard deviation from equations A.1 or A.2,

$(C.F.)_i$ = estimated correction factor based on equations A.4

N_i = the number of effluent phosphorus samples collected from WWTP i during the year.

5.) The standard error of the mean annual phosphorus load at each WWTP was related to the standard error of the mean annual phosphorus concentration computed in step (4). The reasoning was developed from the following equation given by Sachs (1984):

$s.e.(\bar{x}1*\bar{x}_2) = [\bar{x}_1*s.e.^2(\bar{x}_2) + \bar{x}_2^2*s.e.^2(\bar{x}_1)]^{1/2}$ .....[A.6]

where:

$s.e.(\bar{x}_1*\bar{x}_2)$ = standard error of the product of two means, $\bar{x}_1$ & $\bar{x}_2$

$s.e(\bar{x}_1)$ = standard error of $\bar{x}_1$,

$s.e.(\bar{x}_2)$ = standard error of $\bar{x}_2$

Therefore, as:

$\bar{L}_i = \bar{Q}_i*\bar{C}_i$ ....[A.7]

where:

$\bar{L}_i$ = the mean annual flux at WWTP i, as calculated using the MOE procedure,

$\bar{Q}_i$ = the mean annual flow rate at WWTP i,

$\bar{C}_i$ = the mean annual phosphorus concentration at WWTP i.

then:

$$s.e.(\bar{L}_i) = [\bar{Q}_i^2 s.e.^2(\bar{C}_i) + \bar{C}_i^2 * s.e.^2(\bar{Q}_i)]^{1/2} \;\; \ldots\ldots \; [A.8]$$

by assuming that:

$$\bar{C}_i^2 * s.e.^2(\bar{Q}_i) << \bar{Q}_i^2 * s.e.^2(\bar{C}_i) \;\; \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; [A.9]$$

equation A.8 reduces to:

$$s.e.(\bar{L}_i) = [\bar{Q}_i^2 s.e.^2(\bar{C}_i) + \bar{C}_i^2 * s.e.^2(\bar{Q}_i)]^{1/2} \;\; \ldots\ldots\ldots \; [A.10]$$

an equation for which all the parameters are known can be estimated. Justification for the assumption, equation A.9, is found from values for the two terms computed for the three Metro Toronto WWTPs:

WWTP:	Value of Terms:	
	$C_i^2 * s.e.^2(Q_i)$:	$Q_i^2 * s.e.^2(C_i)$:
Main	82.1	1448.0
Humber	18.4	454.6
Highland Creek	0.5	6.3

In all three cases, the values of the term on the left is less than 10% of the value of the term on the right.

6.) The MOE procedure for calculating the mass of phosphorus discharged to a basin from all WWTPs in the basin can be expressed as:

$$L = 365 * \sum_{i=1}^{p} \bar{L}_i \;\; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; [A.11]$$

where: L = the total mass of phosphorus;

$\bar{L}_i$ = the average daily phosphorus mass flux at WWTP i

p = the total number of WWTPs in the basin.

The precision for the basin loading, based on the definition provided by equation 2.4, is:

$$\%dL = 1.96*[\text{s.e.}(\sum_{i=1}^{p} \bar{L}_i)/\bar{L}]*100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [A.12]$$

Based on relationships provided by Sachs (1984):

$$\text{s.e.}(\sum_{i=1}^{p} \bar{L}_i) = [\sum_{i=1}^{p} \text{s.e.}^2(\bar{L}_i)]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [A.13]$$

7.) The aggregate annual mean phosphorus concentration for a basin is the total phosphorus load to the basin divided by the total flow to the basin:

$$\bar{C} = (\sum_{i=1}^{p} \bar{L}_i/(\sum_{i=1}^{p} \bar{Q}_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [A.14]$$

where: $\bar{C}$ = the aggregate annual mean phosphorus concentration per basin;

$\bar{L}_i$ = the mean daily phosphorus load at WWTP i,

$\bar{Q}_i$ = the mean daily flow at WWTP i,

p = the number of WWTPs in the basin greater than 4546 m^3/d.

Based on relationships provided by Sachs (1984):

$$\text{s.e.}(\bar{C})=(1/\Sigma\bar{Q}_i)^2*[(\Sigma\bar{L}_i)^2*\text{s.e.}^2(\Sigma\bar{Q}_i)+(\Sigma\bar{Q}_i)^2*\text{s.e.}^2(\Sigma\bar{L}_i)]^{1/2} \quad ..[A.15]$$

as shown by Table A.7.1, for the three Metro Toronto WWTPs:

$$(\Sigma\bar{L}_i{}^2*\text{s.e.}^2(\Sigma\bar{Q}_i) \ll (\Sigma\bar{Q}_i)^2*\text{s.e.}^2(\Sigma\bar{L}_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [A.16]$$

Accordingly, equation A.15 reduces to:

$$\text{s.e.}(\bar{C}) = \text{s.e.}(\Sigma\bar{L}_i)/(\Sigma\bar{Q}_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [A.17]$$

The precision of the annual aggregate phosphorus concentration is therefore:

$$d_C\% = 1.96*[\text{s.e.}(\bar{C})/\bar{C}]*100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [A.17.1]$$

$$= 1.96*[\text{s.e.}(\Sigma\bar{L}_i)/(\bar{C}*\Sigma\bar{Q}_i)]*100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [A.17.2]$$

From equation A.14:

$$d_C\% = 1.96*[\text{s.e.}(\Sigma\bar{L}_i)/(\Sigma\bar{L}_i)]*100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [A.18.1]$$

$$= d_L\ \% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [A.18.2]$$

In words, values for precision for the total basin loading also apply to the precision for the annual aggregate phosphorus concentration.

Table A.7.1 Comparison of Terms to Examine Assumption Given in Equation A.16

Flow Values:

WWTP:	$\bar{Q}_i$	s	n	s.e.($\bar{Q}_i$)
Main	682.3	150.9	348	8.09
Humber	378.6	75.6	354	4.02
Highland Creek	163.3	17.8	365	0.93
$\Sigma\bar{Q}_i$:	1224.2			
s.e.($\Sigma\bar{Q}_i$):	9.08			

WWTP:	$\bar{L}_i$	s	n	s.e.($\bar{L}_i$)
Main	795.5	883.4	333	48.41
Humber	393.8	273.9	350	14.64
Highland Creek	124.6	50.1	354	2.66
$\Sigma\bar{L}_i$:	1313.9			
s.e.($\Sigma\bar{L}_i$):	50.7			

$(\Sigma L_i)^2 * s.e.^2(\Sigma Q_i)$:	$1.47*10^8$	4%
$(\Sigma Q_i)^2 * s.e.^2(\Sigma L_i)$:	$3.84*10^9$	